STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
DIVISION OF NEW TECHNOLOGY,
MATERIALS AND RESEARCH

OFFICE OF TRANSPORTATION MATERIALS AND RESEARCH

WIND LOADING AS A FATIGUE FACTOR ON LIGHTING STANDARD MOUNTING BOLTS

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TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
FHWA/CA/TL-89/06		

4. TITLE AND SUBTITLE	5. REPORT DATE
Wind Loading as a Fatigue Factor on Lighting Standard Mounting Bolts	June 1989
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Kenneth Pinkerman	8. PERFORMING ORGANIZATION REPORT NO. 637330
9. PERFORMING ORGANIZATION NAME AND ADDRESS Division of New Technology, Materials and Research Sacramento, California 95819	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. F85TL25
12. SPONSORING AGENCY NAME AND ADDRESS California Department of Transportation Sacramento, California 95814	13. TYPE OF REPORT & PERIOD COVERED Final 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highways Administration

16. ABSTRACT

The objective of this project was to characterize the relationship between stress range, frequency of application, and cumulative cyclic loading of properly installed lighting standard anchor bolts under a variety of wind speeds and directions.

Measurements were made for wind conditions versus lighting standard anchor bolt tension loading. In addition, simultaneous readings for accelerations of the luminaire were recorded. Over 250 million data points were taken over a one-year period. These were reduced to 1.65 M bytes of Lotus 1-2-3 data filed on 5 1/4-inch floppy disks. The files contain min/max, average, and standard deviation for wind speed, wind direction, anchor bolt loading, acceleration, and strain on the pole surface.

The high-strength anchor bolt assembly for a Caltrans Type 31 lighting standard is a conservative design. Wind loads experienced during this project did not produce a significant stress in the anchor bolts of a Type 31 lighting standard with a nonslip base design and a 20-or 30-foot arm.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Stress, strain, wind load, lighting standards, vortex shedding, FFT analysis, fatigue failure, bolt stress, high-strength bolts, anchor bolts.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. SECURITY CLASS. (OF THIS REPORT)	20. SECURITY CLASS. (OF THIS PAGE)	21. # OF PAGES	22. PRICE
Unclassified	Unclassified		

DS-TL-1242 (Rev. 6/76)

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NOTICE

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English Unit	Multiply By	To Get Metric Equivalent
Length	inches (in) or (")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft) or (')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic yards (yd^3)	3.785 .02832 .7646	litre (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lb) kips (1000 lb)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lb) foot-pounds (ft-lb)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi) pounds per square foot (psf)	6895 47.88	pascals (Pa) pascals (Pa)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (°F)	$\frac{°F - 32}{1.8} = °C$	degrees celsius (°C)
Concentration	parts per million (ppm)	1	milligrams per kilogram (mg/kg)

ACKNOWLEDGEMENT

The author appreciates the technical support provided by Del Gans and Walt Richards during prototype testing and field installation of sensors. In addition, the efforts of Bob Moscowitz, Charles Frazier, Dick Wood, John Dusel, and Gene Lombardi during the data analysis phase are highly appreciated.

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1. INTRODUCTION

This research was conducted in response to failures of Caltrans Type 31 lighting standard high-strength anchor bolts in field installations where wind load exposures were higher than normal. In a previous study, the anchor bolt was tested in laboratory conditions for physical load carrying characteristics and fatigue life. However, this study did not take measurements under actual field conditions. The contribution to the failures by wind loading of the assembly could not be determined from the laboratory tests alone. The purpose of this research was to provide the design engineer with field measurements of anchor bolt loading in relation to the wind conditions so that this determination can be made.

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2. BACKGROUND

Recent studies have documented the fatigue characteristics of commonly used anchor bolts and cap screws, both mild steel (ASTM A307) and high-strength (ASTM A449) (1). These published stress range/cycles-to-failure curves provide information about the bolt materials' resistance to cyclic loading. To apply this information to the physical world the source, magnitude, number of cycles, and frequency of cyclic loading must be documented. The A449 high strength anchor bolts are the type investigated for cyclic fatigue loading in this study. They are a small percentage of the population of anchor bolts, which are mainly type A307. The Caltrans Type 31 lighting standard uses the A449 anchor bolts and is the principle type examined.

One concern of the design engineer is the wind-induced vibration which may generate a significant cyclic stress loading on the structure and its mounting fasteners. The main driving forces that produce the structure vibration are wind forces (static and gusts) and vortex shedding (2). Other causes of damaging vibration may include ground based vibration produced by heavily loaded trucks, earthquakes, or construction-related operations. These vibrations are normally short-lived and individually produce no long-term fatigue effects as the number of stress cycles is very small.

The term fatigue is defined as "the process of progressive localized permanent structural change occurring in a material subjected to conditions which produce fluctuating stresses and strains at some point or points and which may culminate in cracks or complete fracture after a sufficient number of fluctuations" (3).

If the number of stress cycles in the fastener and the stress range to which the fastener is subjected exceed those values which produce small fatigue cracks for that material, then the potential for early fatigue failure is very high (4,5). Under extreme wind conditions, the static loading force is accompanied by randomly fluctuating gusts that may induce vibratory motion in the structure. This variance of the "drag" force and its dynamic effects are addressed in the AASHTO Design Specifications (6) as a 1.3 gust factor applied to the calculated design static wind loading. In many cases this factor appears to be insufficient (7).

The most continuing and damaging vibration is often caused by low to moderate velocity winds. A few months exposure to steady wind velocities around 7 to 30 mph will sometimes destroy a lighting structure and its mounts that otherwise have sufficient strength to withstand a few applications of static forces corresponding to 130 mph peak wind speed (8). These vibrations are caused by Karmon vortices. Karmon vortices cause vibrations in a plane perpendicular to the wind velocity, because of a resonant shedding of wind around the surface. This may cause the structure to undergo millions of stress cycles in a short period of time.

Design of lighting standards for wind loading in California is mostly empirical and field data that document real frequencies and forces are not available. Actual measurements of forces experienced under various wind conditions will provide the designer with a sound basis to optimize the existing design and modify it for a new lightweight standard that may be required in the future.

With the large inventory of lighting standards on our highway system, many having been in service for many years, it seems appropriate that a reevaluation of fatigue life of their anchor bolts be conducted. The information provided by the results of this study may be used to establish a preventive maintenance program to reduce the potential liability for premature failure of in-place lighting standards.

3. RESULTS AND CONCLUSIONS

Over 250 million data points were taken over a one-year period (February 1987-April 1988). These were reduced to 1.65 M bytes of Lotus 1-2-3 data files, on 5 1/4-inch floppy disks. The files contain min/max, average, and standard deviation for wind speed, wind direction, anchor bolt loading, accelerations, and strain on the pole surface.

The results are as follows:

1. The anchor bolt assembly for the Caltrans Type 31 lighting standard is a conservative design for winds experienced during this testing. Wind loads observed during this project did not produce a significant stress in the 1-inch diameter anchor bolts of a Type 31 lighting standard (non-slip base type) with a 20 or a 30-foot arm. The bolt cyclic stress ranges (maximum stress minus minimum stress equals stress range at that wind speed) measured in this research are much lower than the fatigue limits determined by laboratory testing. The highest tension stress and stress range in the rear anchor bolt is as follows:

Arm	Peak Wind Speed Measured	Max Bolt Stress	Calc Bolt Stress*	Max Stress Range
20 ft.	44 mph	8540 psi	9540 psi	7580 psi
30 ft.	39 mph	11060 psi	13550 psi	6080 psi

* Traffic Signal & Lighting Standard Stress Analysis Program

2. A Type 31 lighting standard with a triangular slip base has two back anchor bolts to carry the arm dead load and the dynamic load from wind forces. Therefore, the anchor bolts in this application are not as susceptible to fatigue failure, as the non-slip base version, because of lower stress in the bolts.

3. Data taken during critical wind speeds (theoretical) for vortex shedding for the Type 31 lighting standard do not show significant changes in tension loads in the anchor bolts with either arm length. The vibration frequency and X,Y,& Z accelerations do not show patterns significantly different from other observed wind speeds. The tapered section of the pole and arm do not allow sufficient uniform surface to generate measurable vortex shedding forces.

4. The measured natural frequency of the Type 31 lighting standard with a 20-foot arm (Type 31/20) is 1.07 Hz and three other significant vibration frequencies occur at 2.45 Hz, 8.67 Hz, and 12.94 Hz.

5. The measured natural frequency of the Type 31 lighting standard with a 30-foot arm (Type 31/30) is 0.78 Hz and three other significant vibration frequencies occur at 1.80 Hz, 5.37 Hz, and 10.27 Hz.

6. Maximum wind velocities during wind gusts, at the Benicia test site, can vary by as much as 3.4 times the minimum wind speed in a 12-second interval. The maximum wind speed was commonly double the minimum, in the same 12-second time frame, when the average wind speed was 20 to 25 mph.

7. The luminaire maximum accelerations (peak to peak, measured at the center of gravity), when mounted on a Type 31/20 lighting standard, are +3.2 g to -3.5 g for Ax, and +0.6 g to

-1.4 g for Ay. For the Type 31/30 lighting standard, with the same luminaire, the maximum accelerations are +2.2 g to -2.1 g for Ax, and +0.5 g to -1.3 g for Ay. See Figure 17, page 32, for x & y orientation.

4. IMPLEMENTATION

The results from this research have produced field data for stress levels and stress cycles that affect the tension fatigue loading on anchor bolts for lighting standards subjected to varying wind load conditions.

The results are available on several edited IBM PC 5 1/4-inch floppy disks in Lotus 1-2-3 data files for the California Department of Transportation (Caltrans) Office of Structure Design and to other researchers to use as a bolt loading data base and to provide luminaire acceleration information. The wind force data base can be used for estimating fatigue life of lighting standard fasteners that will enable designers to validate or revise wind loading models, verify or revise design theories, develop a test cycle for fatigue research or new design acceptance criteria, and possibly institute a preventive maintenance program for existing installations.

5. DISTRICT WIND LOAD PROBLEM SURVEY

A survey of traffic and maintenance employees in the 11 Caltrans districts and headquarters office was conducted. The questions asked dealt with the occurrence of failures of lighting standards of any type, but in particular, failures of anchor bolts. The lighting standard type and arm length, location, type of failure, probable cause, and whether wind was a contributing factor were the specific items covered. Table I shows the results of this survey.

TABLE I

DISTRICT SURVEY

DISTRICT'S	1	2	3	4	5	6	7	8	9	10	11
Failure	Y	Y	Y	Y	N	Y	N+	Y	N	Y	Y
Pole Type	31	31	31	31	*	31	15	31	*	31	31
Gnd/Str*	G	G	G	G/S	*	G	S	G	*	G	G
Arm	30	30	30	30	*	30	20	30	*	30	30
Wind	N	Y	Y	Y	*	Y	N	Y	*	Y	Y
Install #	Y	Y	N	N	*	Y	Y	N	*	N	N

* Ground based(G) or structure mounted(S) light standard

\# Installation errors or related failure.

\+ Arm failure.

Y Yes

N No

In most cases the failure was noticed when the lighting standard tilted toward the travel way. This was caused by the fracture of the rear anchor bolt in the triangular base plate of the Type 31 steel pole. The Type 31 pole with the 30-foot tapered arm (Type 31/30), without the slip base (Fig. 1), was the typical configuration when failures occurred. This design places the highest tension load (moment due to the arm and luminaire dead load and the tension component of the wind load) on the single anchor bolt on the back side of the pole away from the arm. The Type 31 lighting standard with the 30-foot arm has been phased out over the last 5 to 10 years due to anchor bolt failures. They have been replaced with Type 31 lighting standards with 20-foot arms.

In contrast, the Type 31 lighting standard slip base mounting has two anchor bolts on the side away from the arm (Fig. 2); thus, the tension load is divided between them. The slip base assembly uses a single clamping bolt on the back side to hold the plates together. This bolt is a high-strength bolt that is torqued to a specific preload which lessens fatigue failures.

Some past failures of Type 31 lighting standard anchor bolts were not clear-cut in nature, the anchor bolts appeared to be corroded when assembly occurred or showed signs of partial fracture for some other reason. At one point in time, Caltrans permitted 7/8-inch diameter ungalvanized high-strength anchor bolts for Type 31 lighting standards. Without galvanizing and occasionally lacking complete grouting around the anchor bolts, corrosion was accelerated. The failure could have occurred because of high wind speeds and fatigue accumulation or exceedance of the yield strength of the reduced area of the bolt.

The original high-strength anchor bolt size for the Type 31 lighting standard was 7/8-inch diameter. After several failures were noted, the design diameter was increased to 1 inch.

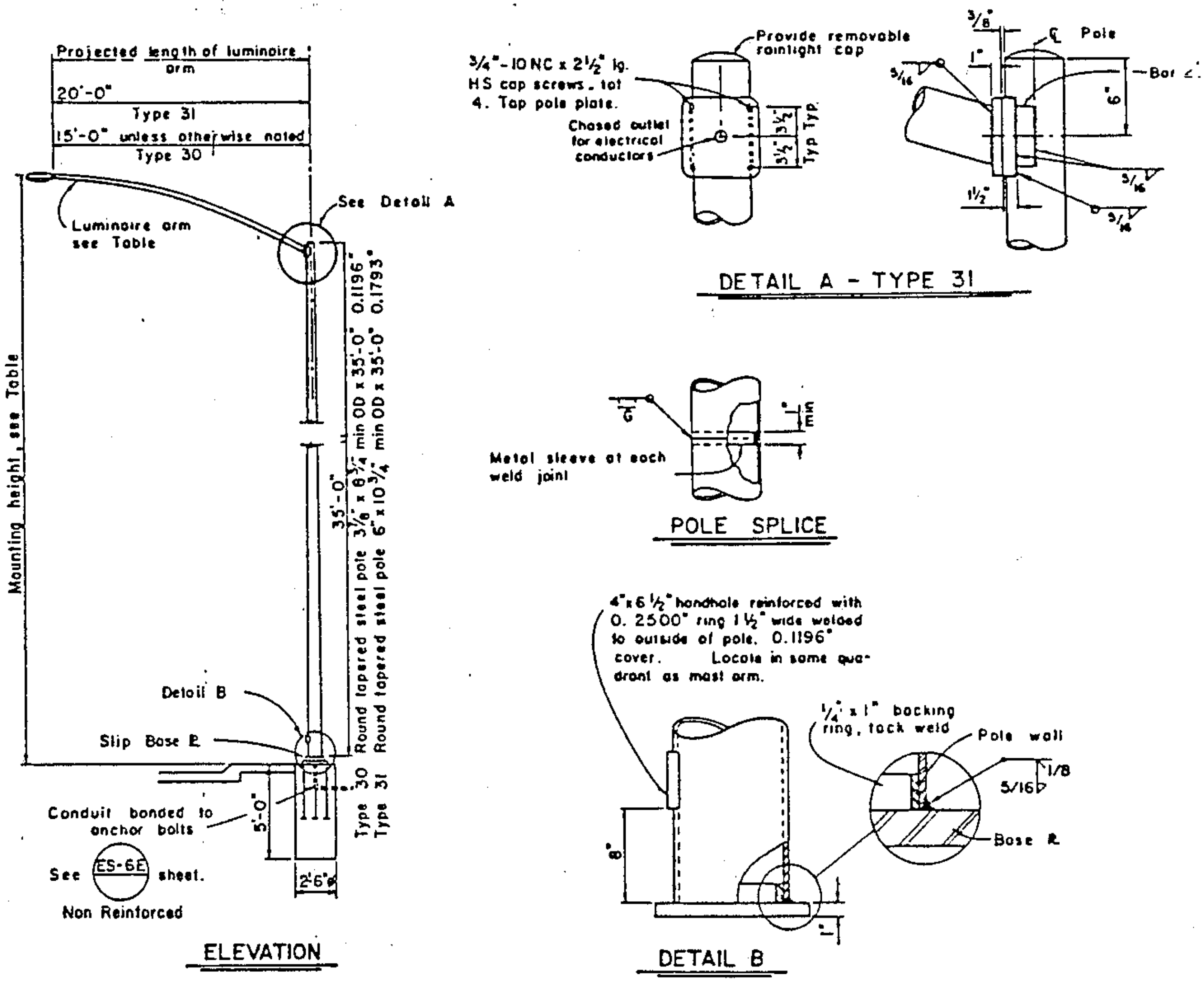


Figure 1. CALTRANS TYPE 31 LIGHTING STANDARD

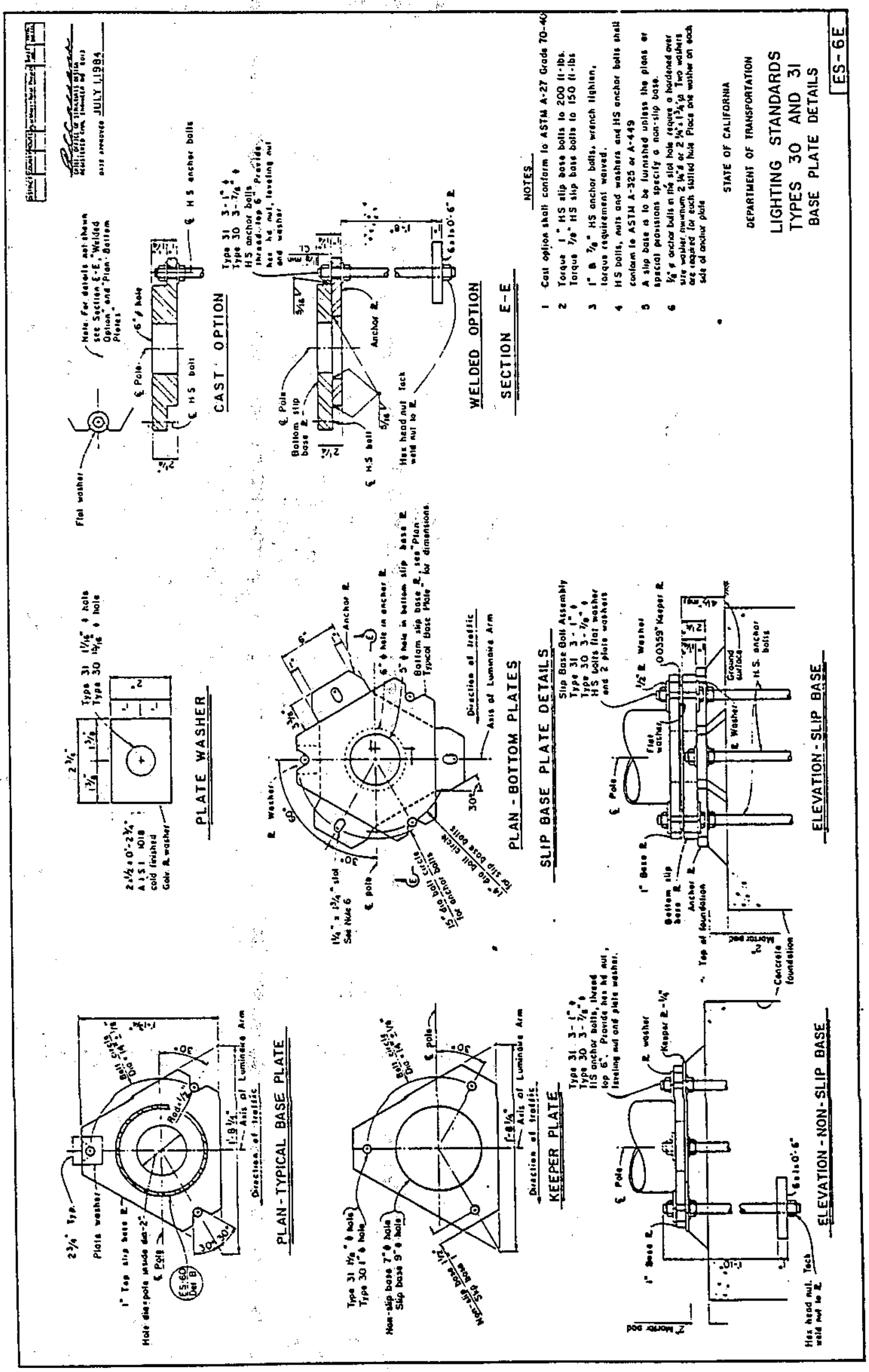


Figure 2. SLIPBASE DETAIL

Additional failures required the arm length to be decreased to 20 feet from the standard 30-foot arm to reduce stress on the anchor bolts. No known failures have occurred since both changes have been placed in the specifications.

In addition, the Caltrans Type 15 pole was examined for potential anchor bolt loading problems. This type pole has a square base plate with four anchor bolts. It is used with a maximum arm length of 15 feet and can be mounted with or without a slip base. The anchor bolts are A307 mild steel (11-inch bolt circle diameter) in contrast to three A449 high-strength steel bolts (14-inch bolt circle diameter) for the Type 31 light standard. Therefore, with two back bolts sharing the tension load and the fact that the mild steel bolts exhibited superior fatigue life to high-strength bolts for all stress ranges up to 36 kpsi (1), it was determined that the chance for fatigue failure in ground based anchor bolts was very minimal.

6. CALIFORNIA WIND PROFILES

Wind records were researched for the areas that had light standard failures. The survey results pointed to three general areas of wind loading problems for existing lighting standards. The areas are the mountainous section of District 02 near Weed along I-5, the straits in the coast range near the San Francisco Bay, and the high desert passes in Southern California that conduct Santa Ana winds toward the ocean. Yearly wind speed average, percentage of calms, wind speed average for each month, wind gusts, and percentage of time wind from one direction were some of the data investigated for each potential station site.

Two main data sources were used to determine the highest potential location for testing for a combination of steady winds for vortex shedding and high wind velocities which would allow us to look at gust factors and high static loading. The California Energy Commission Wind Atlas (9) and the report Wind in California (10) published by the California Department of Resources, give percentages of occurrence of wind speeds, calms, average monthly wind speeds, peak winds and gusts, and wind direction. These references covered 400 to 500 different measuring locations. These data, along with historical Caltrans wind records taken for environmental impact assessments and wind energy evaluation, were used as a guide to determine the initial testing location.

The Caltrans wind data are taken by a mechanical weather station as wind run (wind run is the equivalent length of air passage in a specific time segment), and wind direction, usually at the U.S. Weather Bureau standard height of 10 meters. This data is reduced by a digitizing system, recorded on magnetic tape, entered into the SAROAD data system, and then are accessible by the TIMESHARE mainframe computer system.

7. TEST SITE SELECTION

The site to be used for testing strain/stress in the light standard anchor bolts would have to have continuous winds, from the same quadrant, between 8 to 20 mph to generate significant vortex shedding loading (11) and potential for winds over 40 mph for pressure loading. The other important aspects that determined the location were: access to electrical power, logistics, security, phone lines, clear fetch for wind, space for parking a van to house the computer and signal conditioning electronics, good local wind records, and preferably a Caltrans facility.

To reduce the candidate sites, the wind speed data were screened for inaccessible sites, mountain tops, points out in the ocean, and islands. The next good indicator was lowest percentages of calms as we were looking for consistent winds in the speed range of theoretical vortex shedding for the lighting standard. Then the data were examined for highest percentages of winds over 7 mph as groups representing 7 to 10 mph, 11 to 15 mph, 16 to 20 mph, and over 20 mph. All data stations exhibited very low (<0.1%) percentages over 40 mph. Station locations considered would have to have 40 to 50 percent of the wind speeds in the 7 to 30 mph range and have potential for winds over 50 mph. This procedure reduced the number to four potential areas where meteorological conditions were of interest.

Sites in eight different locations in northern California were considered along with two in southern California for high winds. The high wind sites in southern California were held in reserve as the probability of 50+ mph winds at any one location is very low, roughly one in 25 years (10).

The northern California sites were: Altamont Pass, Carquinez Strait, Golden Gate Bridge at the north end, Fairfield, Benicia Bridge, Pittsburg/Antioch area, Richmond Bridge at the north end, and the Dixon area. Each area met the requirements for windy conditions and all were within reasonable travel distance of the Transportation Laboratory (TransLab). Each was examined for the desired characteristics. Some of the site problems encountered were extreme high voltage power lines nearby, limited access, limited area for installation, physical obstacles which would interfere with wind flow patterns, poor local wind data, or the lack of security.

The location chosen was the Caltrans facility at the Benicia Toll Bridge on I-680 in Caltrans District 04. Caltrans has wind history on this site for more than two years from a previous energy study. The Benicia Toll facility is located in an opening between the Central Valley and the Carquinez Strait, northeast from the San Francisco bay, that acts like a pipeline for wind between the two areas (Figure 3). Wind speeds may be locally strong in regions where air is channeled through a narrow opening such as the Carquinez Strait (12). This makes the wind direction very consistent and predictable, either in or out of the valley depending on frontal passage or hot air rising over the valley floor.

The Caltrans facility at this location is on a point of land that projects out to the Benicia Bridge and provides a clear wind fetch in the primary two wind directions. District 04 had just removed an old warehouse on the elevated site and left a clear parking lot area (Figure 4). The light standard was mounted on the southeast side of this parking area above the toll plaza on the north end of the bridge.

This site met the other requirements with a single exception, the potential for very high winds (excess of 50 mph) was not confirmed. Past Caltrans wind records were taken with a wind run sensor which did not record gusts of short duration (14).

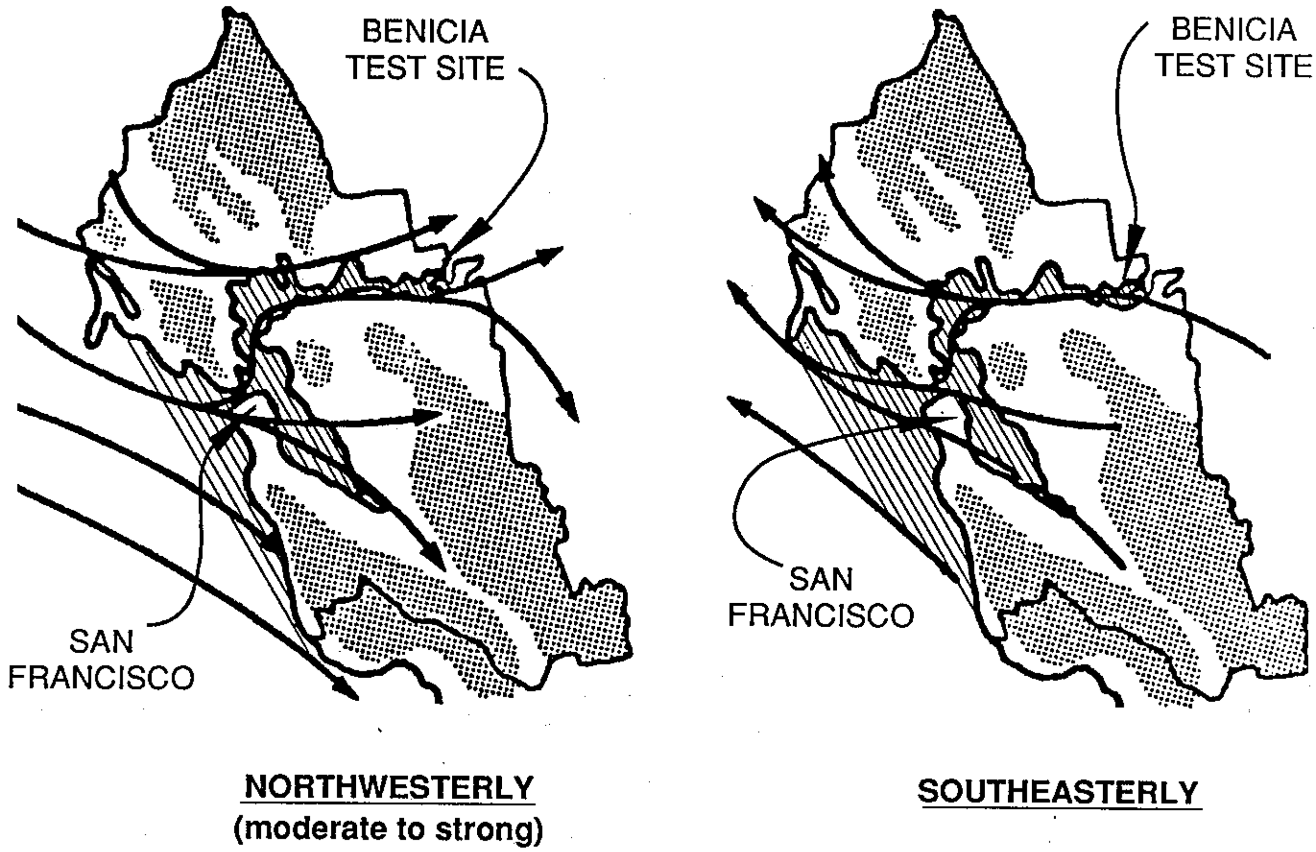
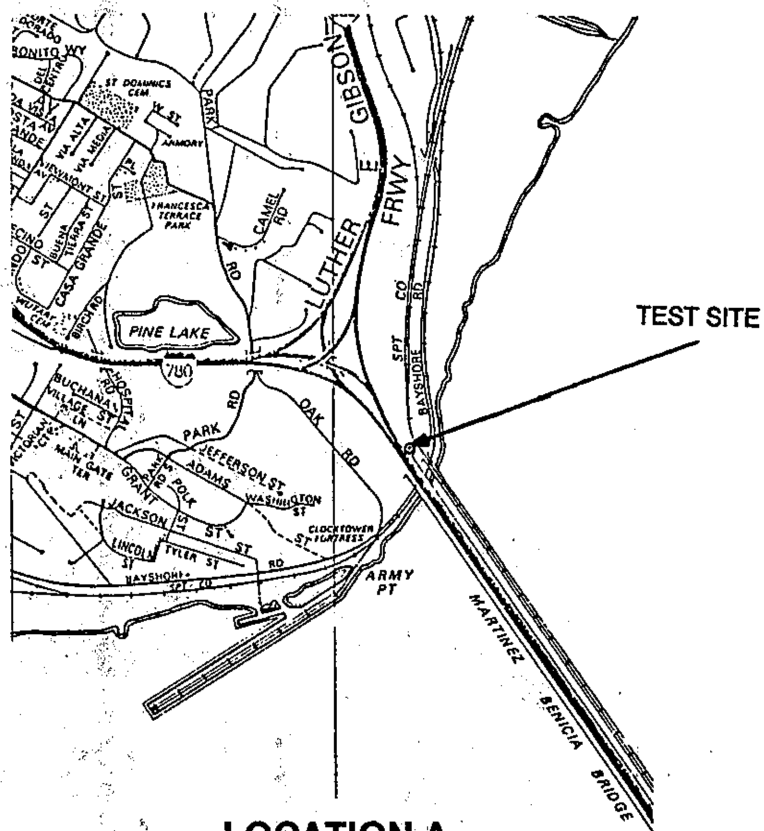


Figure 3. WIND FLOW PATTERNS



LOCATION A

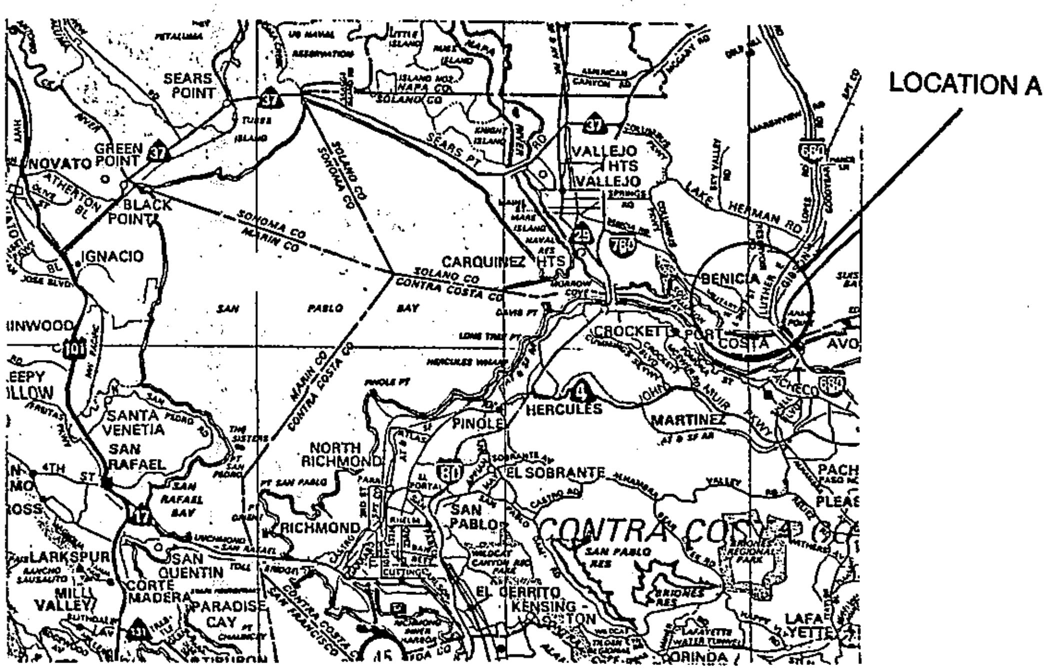


Figure 4. TEST SITE MAP

8. LIGHT STANDARDS

The district survey pointed out that anchor bolt failures occurred when Type 31 light standards were mounted without slip bases and using 30-foot arms. See Tables II and III for specifications. Currently, Caltrans is using a maximum arm length of 20 feet on this lighting standard because of these failures.

TABLE II
POLE DIMENSIONS

Pole Type	Height	Outer Dia. Base	Outer Dia. Top	Thickness	Anchor Bolts
15	30'	8"	3.875"	0.1196"	1" dia.x36 (A307)
31	35'	10.75"	6"	0.1793"	1" dia.x36 (A449)

TABLE III
LUMINARIE ARM DIMENSIONS

Arm Length	Thickness	Minimum Dia. at Pole	Minimum Dia. at light	Luminaire Mounting Height
15'-0"	0.1196"	4.25"	2.375"	34'-3"
20'-0"	0.1793"	5"	2.375"	37'-0"
30'-0"	0.1793"	6.5"	2.375"	40'-0"

Taking this design information into consideration, this research has been focused on the worst case of no slip base (single anchor bolt away from the arm) and the longest arm (20 feet) and the current style of luminaire with the transformer in the light head. This luminaire is of the flat lens style with a slightly narrower profile to the wind. The luminaire was an American Electric Series 25/26 model, weighing 38 pounds.

The anchor bolts that are used for the Type 31 light standard are 1-inch diameter high-strength bolts with the specifications shown in Appendix A. Table IV shows the test results of a sample of the bolts used for this research.

The anchor bolts were tested under the following ASTM methods:

Mechanical Tests	--	A449, F606
Chemical Tests	--	A449, A751
Galvanizing	--	A449, A153, B695
Thread Tolerance	--	ANSI B1.1, Class 2A before galvanizing.

The nuts were tested under the following ASTM methods:

Mechanical	--	A563, A194, A370
Thread Tolerance	--	Overtapped above ANSI B1.1, Class 2B, per Caltrans 86-2.03

TABLE IV
ANCHOR BOLT AND NUT TEST RESULTS

	Yield Point (Spec.)	Ultimate Load (Spec.)	Hardness (Spec.) Rockwell C
1" Anchor Bolt ASTM A449	74,000 lbf (>55,750)	83,650 lbf (>72,700)	25.9 (25-34)

	PROOF LOAD (SPEC.)	
1" Nut, Grade 2H ASTM A194	106,000 lbf (No thread stripping @ 130,000 lbf)	25.9 (24-38)

Thickness of Galvanized coating -- 0.0095 in. equals 5.6 oz/sq ft (>1.0 oz/sq ft)

The anchor bolts and nuts met all but one of the specifications. The maximum pitch diameter of the bolts were slightly under specification after the zinc was removed. This was judged not to be a problem for the research that we were conducting. (See Appendix A & B for Test Reports.)

9. EQUIPMENT SELECTION

The next step involved determining the method and type of sensors to measure and record the strain/load in the anchor bolt. Anchor bolt tension loadings were measured by strain gages mounted internally. The anchor bolts were center drilled by StrainSert Co. and the strain gages applied to the inside circumference of the small center hole. The gage vertical location was placed just above the plane of the surface of the concrete in which the bolts were inserted (Figure 5). This gives a tension/compression loading value for the pole's three anchor bolts without bias from the leveling nuts or the concrete base.

The strain gage sensors were calibrated by StrainSert Co. (Appendix B), after installation in the anchor bolts, to read as kips/millivolt change. This calibration method compensates for the hole drilled to place the gage at the specified depth in the bolt. The bolt stress is calculated based on the minor diameter of the threaded portion of the bolt, ie., 0.606 square inches (6). As the bolt is calibrated to read true loading with the gage hole, the represented stress for the anchor bolt in field usage can be calculated using the above minor diameter.

The acceleration was measured by Statham Instruments Accelerometers, Model A301-5-350, with a range of (+) or (-) 5 g. These were calibrated by the Electronics Branch at TransLab before installation in the luminaire housing. X,Y,Z components of the true vector acceleration were taken by separate sensors and recorded as individual signals.

The signals from the strain gages and the accelerometers were conditioned by Measurement Group, Inc. Strain Gage Conditioning Amplifiers, Model 2310. One amplifier system was used for each strain gage and each accelerometer. These systems provided excitation voltage for the strain gages and amplification of the

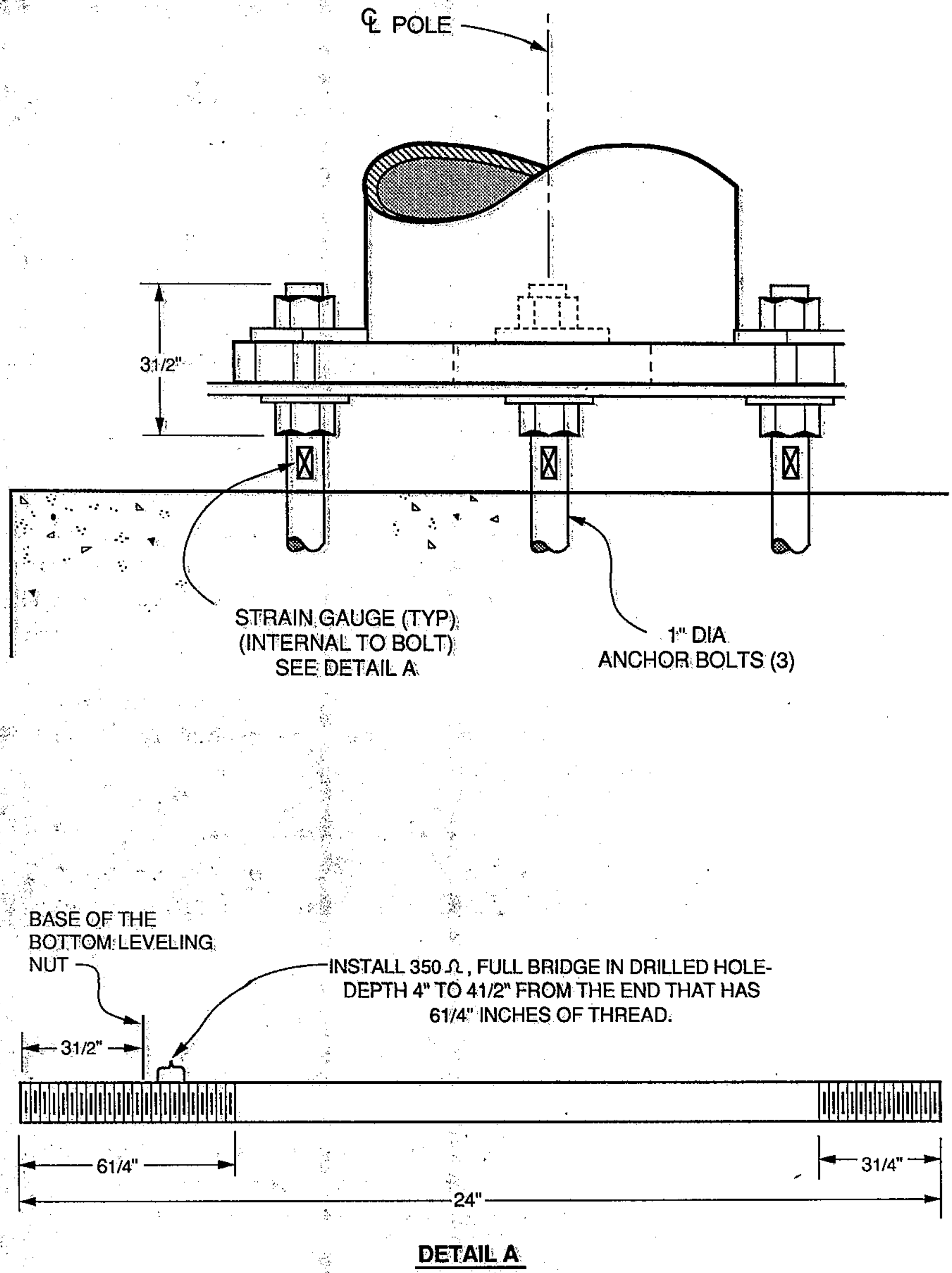


Figure 5. BOLT STRAIN GUAGE DETAILS

resulting signals. This allowed balancing of the bridge circuits for zero voltage and range selection for the signals generated.

The meteorological measurements, wind speed and wind direction, were taken with Climet wind sensors Model WD-012-10, Model WS-011-1, and with a signal translator, Model 060-12. This system was calibrated in TransLab's wind tunnel for a speed range of 5 to 45 mph (Appendix F). The sensors were mounted on a mast, attached to the back of the van, 10 meters off ground level, which placed them within (+) or (-) 1 meter of the height of the luminaire (Figure 6). This is critical as wind speed varies significantly near the ground surface (Figure 7).

The meteorological system output signals were fed simultaneously to a SumX Model SX405 data logger (Figure 8) and the Hewlett-Packard (HP) Model 1000 computer (Figure 9). The SumX data logger read the wind speed and wind direction sensor output once every minute and summarized the data into hourly averages. The summary data were recorded by a built-in magnetic tape cassette recorder. The minicassette (3M DC-1000) could hold one month's wind records. The HP computer took meteorological data 20 times a second and recorded every reading, when control conditions were met, on magnetic tape. These measurements were taken simultaneously with strain and acceleration data. The data were recorded on a HP 9-track reel-to-reel magnetic tape recorder with a maximum tape reel size of 1100 feet.

The HP computer was programmed to generate a switch closure signal to the SumX data logger when either the magnetic tape ran out or the computer shut down for any reason. The switch closure was shown on the data readout of the SumX data logger as a "B" after the standard voltage reading (Figure 10). This signal and the meteorological data could be remotely monitored and accessed by a MultiModem, Model MT212AH2, a Compaq computer, an IBM compatible PC, and telephone lines. The telephone line drop was

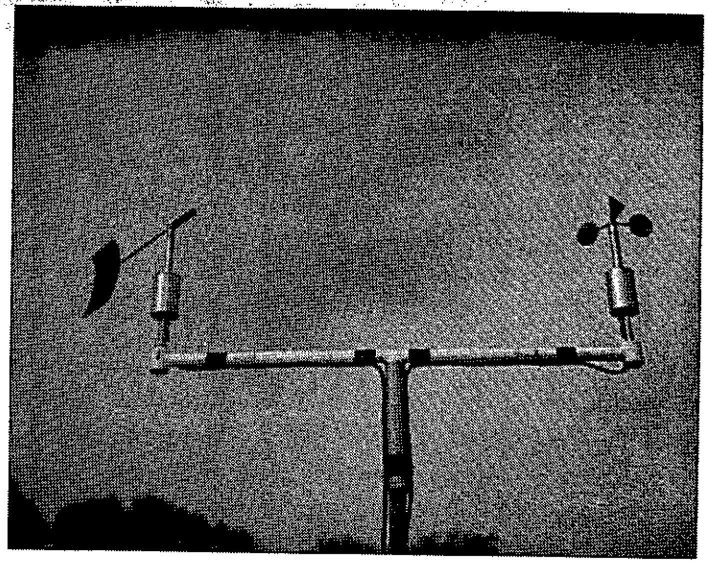


Figure 6. METEOROLOGICAL INSTRUMENTS

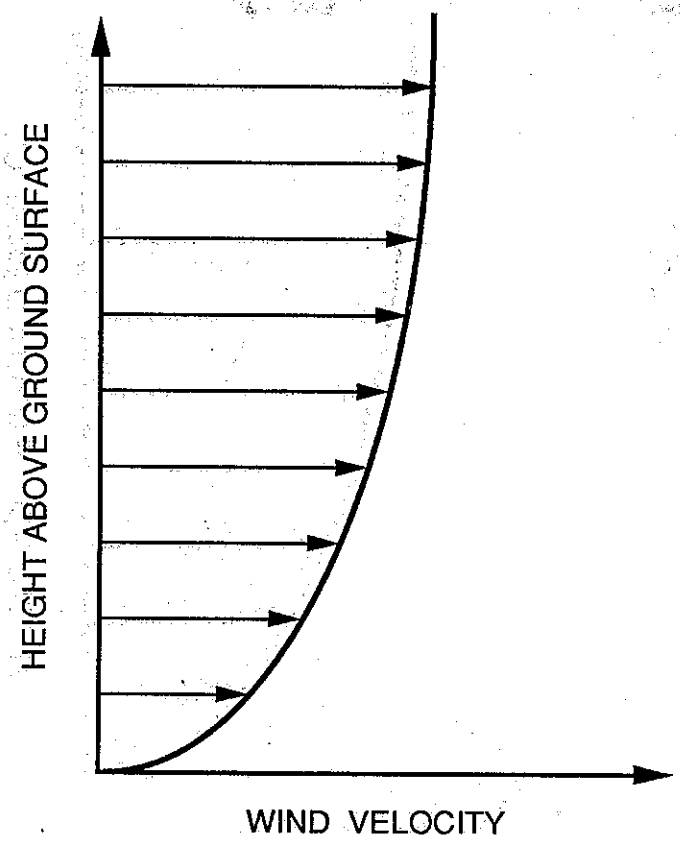


Figure 7. WIND VELOCITY vs HEIGHT

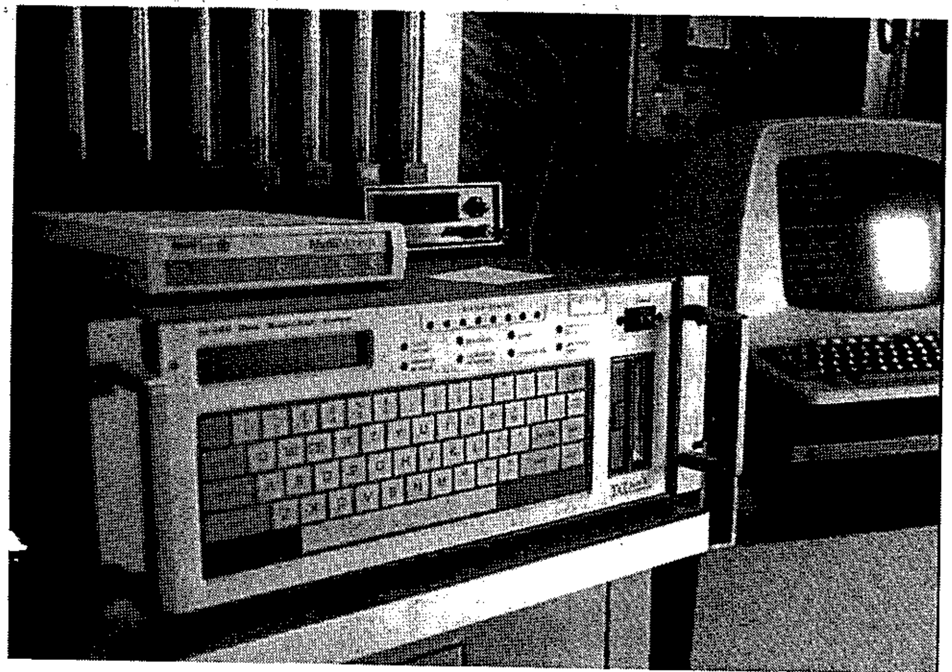


Figure 8. SUMX DATA LOGGER & MODEM

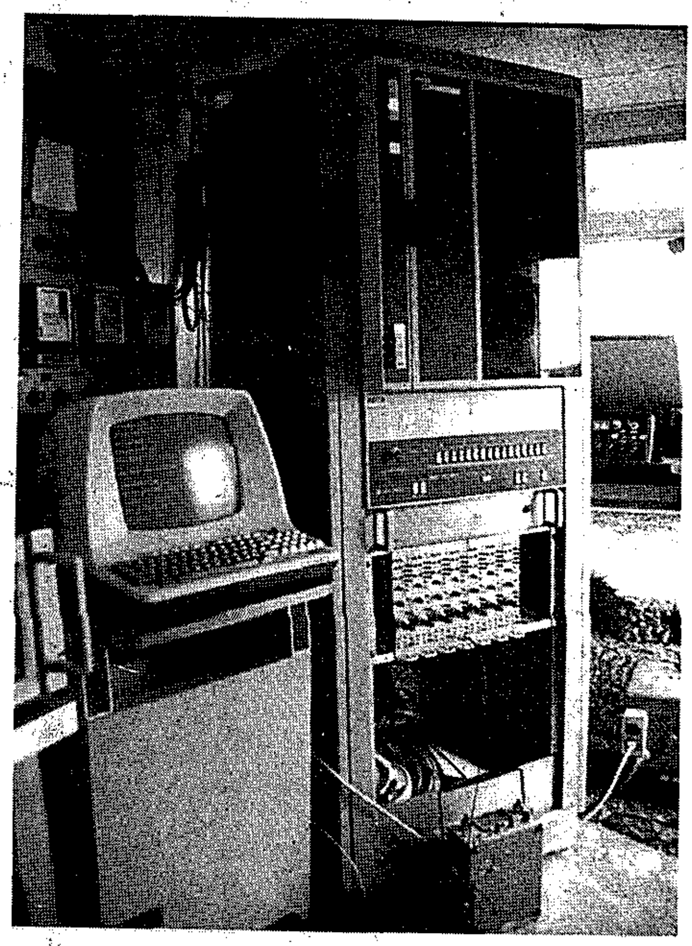


Figure 9. COMPUTER SYSTEM

DAILY SUMMARY 04/02/88 93 BENICIA

****

CHANNEL NUMBER	01	02	03	04
CHANNEL NAME	WD/DEV	WS	CAL	SPD
CHANNEL UNITS	DEG	MPH	VOL	MPH
FULL SCALE VALUE	540	80	5.000	80
ZERO VALUE	0	0	.000	0
INPUT RANGE	5	5	5	5
01:00	266/ 8	8	4.847	8
02:00	268/ 12	7	4.847	8
03:00	278/ 10	8	4.847	8
04:00	274/ 10	9	4.847	9
05:00	274/ 10	10	4.847	10
06:00	272/ 8	10	4.847	11
07:00	268/ 10	11	4.847	11
08:00	268/ 10	12	4.847	13
09:00	268/ 12	12	4.847	12
10:00	270/ 12	12	4.847	12
11:00	272/ 17	9	4.847	10
12:00	270/ 18	10	4.847	10
13:00	271/ 13	14	4.850	15
14:00	268/ 13	16	4.850	16
15:00	269/ 13	14	4.850	15
16:00	267/ 12	14	4.850	14
17:00	265/ 14	13	4.850	14
18:00	262/ 12	14	4.850	15
19:00	257/ 10	17	4.850	17
20:00	260/ 12F	13F	4.837F	13F
21:00	260/ 10	13	4.850B	14
22:00	252/ 13	13	4.850B	13
23:00	250/ 15	12	4.850B	12
00:00	249/ 12	13	4.850B	13
AVERAGE	266/ 12<	12<	4.847<	12<

LAST AUTO CALIBRATION RESULT

ZERO	SPAN	SPAN VALUE

Figure 10. SUMX DATA PRINTOUT

a standard voice quality service and proved very adequate for monitoring the Benicia test site from the TransLab in Sacramento.

The HP computer was an installed part of TransLab's Air Quality Monitoring Van used for system control and data acquisition. For this research project, the van was parked approximately 50 feet from the test lighting standard and provided shelter for the electronic equipment. The contours of the surrounding ground allowed the van to be parked next to a ridge line in the hillside so that it didn't interfere with the site airflow (Figure 11).

The system power was taken from the 220V AC power distribution panel in the District Maintenance fuel pump building. The van power cord was routed around the edge of the parking area and into the rear of the van. The van has its own internal electrical power distribution system and the project's electronic equipment was protected by a large isolation transformer. This minimizes the electrical spikes that could damage the electronic equipment and cause errors in the recorded data. The local power supply company (Pacific Gas & Electric Co.) had supply problems many times during the year of data gathering and power failures during high wind conditions were common.

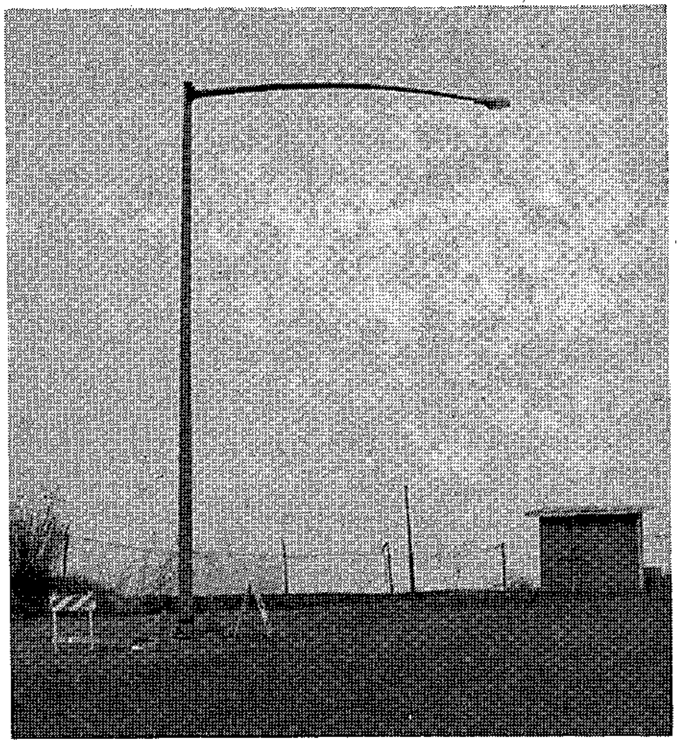


Figure 11. TEST SITE

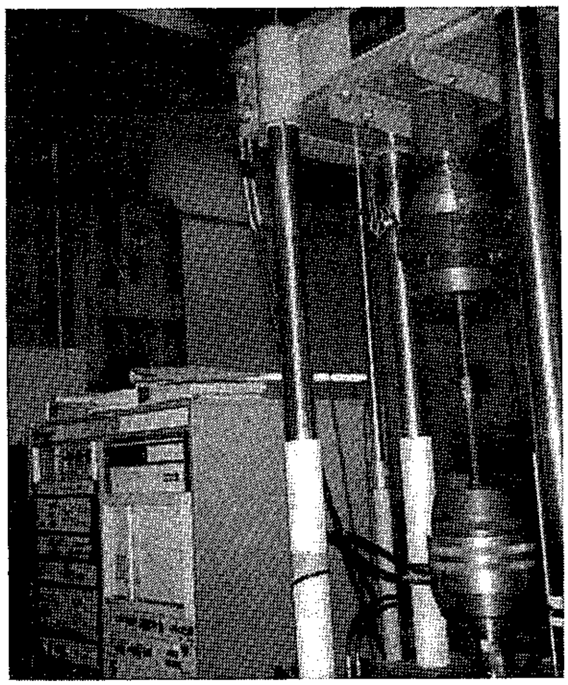


Figure 12. DYNAMIC TEST MACHINE

10. COMPUTER PROGRAMMING

The HP computer program was developed to take electrical signal levels from several types of sensors at selected rates with a minimum of processing and place them on a 9-track magnetic tape for storage and transport to TransLab for analysis. With very high channel sampling rates, strain data at a rate of 100 readings per second and the accelerometers at 500 reading per second, little computer time was available for data processing; only control limits were used. These limits, based on wind speed and direction, told the computer when to start to take data and when to stop, so that magnetic tape storage was optimized.

The computer program was developed in modules to make updates and changes more efficient and timely. It consists of the following modules:

1. Wind Loading Initialization & W Main
2. Timer Routine For Wind Loading - * W Time
3. Wind Load; CAF - Read MT Routine & Storage
4. Multiplexer Data Acquisition Module & W Mux
5. End of Wind Run Routine - W End
6. BCS TTY Driver - No LF After CR Required
7. ASMB,A,B,L,C - Write 1 Record on Tape
8. ASMB,A,B,L,C - Read 1 Record Into Core From Tape
9. 9TRK Mag. Tape Writer - & WMT

This program is designed to provide the operator an interactive display which asks questions that are site and data specific. Location code, Julian day, tape number, wind speed to initiate sampling, and time of day are entered as the program is started. Computer operation commences after the time of day is entered.

Data collection is contingent on meeting the control conditions. Otherwise, the system idles until the wind direction and speed conditions are met. The direction control is predetermined to be (+) or (-) 20 degrees of perpendicular to the lighting standard arm from either side. The speed starting level is entered each time the new data tape is loaded and is usually set at 5 mph increments. When the tape runs out (approximately 1 hour for the standard data recording) the computer halts and displays the halt time on the screen of the terminal. In addition, the computer provides a switch closure to the SumX data logger to signal shutdown. Unfortunately, when shut-down occurs due to power failure, the magnetic tape drive system releases tension on the tape and the computer system can't restart when the power is restored. The SumX data logger output was relied on for recording power failures and signaling the need for restarting the system.

Programming for the SumX data logger was supplied by the manufacturer as part of their general air quality data acquisition package. Some of the input items can be adjusted to individual project needs. For this research, the data channels were limited to the meteorological inputs of wind speed and wind direction. In addition, the SumX logged the power failures as time of occurrence and duration. This documented the gaps in the recorded meteorological data, and when the HP computer system was down for any reason. The SumX system developed hourly averages and daily summaries that were recorded on minicassette tape for downloading by telephone modem in conjunction with a PC at TransLab. By downloading on a regular basis (once a week), the tape does not need to be changed.

11. SYSTEM CHECKOUT

After developing the necessary software to allow the HP 1000 series minicomputer to access and record the sensor signals, there was the need to test the program. This mock-up would insure proper operation with the sensors and signal conditioning before installation at the field site. In particular, the time within the program to function and operate with only 16k of memory was in doubt. Another question was the ability of the sensors to see the low-level strain expected from the calculated theoretical values.

A lab test was developed using a 2-foot piece of reinforcing bar that already had a strain gage bonded to a machined spot on the middle surface. The projected values for strain and frequency of loading were calculated for the steel bar and programmed into the automated dynamic tensile test machine (Figure 12), in the Structural Testing Lab at TransLab. This cyclic loading with a similar strain gage bonded to the surface and measuring the electrical signal through the mock-up would duplicate the field system. This simulation took voltages from the sensor bridge circuit, through the signal conditioning, to the van HP minicomputer and on to magnetic tape. During the testing, different filters were electronically inserted into the signal system to judge the possible benefits.

The data tape was then removed and taken to the TransLab Air Quality Lab HP minicomputer and read, using a hard wire feed, into a Compaq PC and placed on a 30-megabyte hard disk. The data were backed up with a PC data/software cassette recorder to write the information on a 3M type 100 cassette tape for long-term storage. Using the software program GRAPHER, the initial data for each channel were drawn on a Houston Institute X/Y plotter.

These plots were examined for the expected sine wave, frequency, and the amplitude of the signal (Figure 13). These tests proved the soundness of the hardware system, the programming, the sensor sensitivity, and the accuracy of the output. It was decided that filtration requirements would depend on the background signal noise encountered in the field installation.

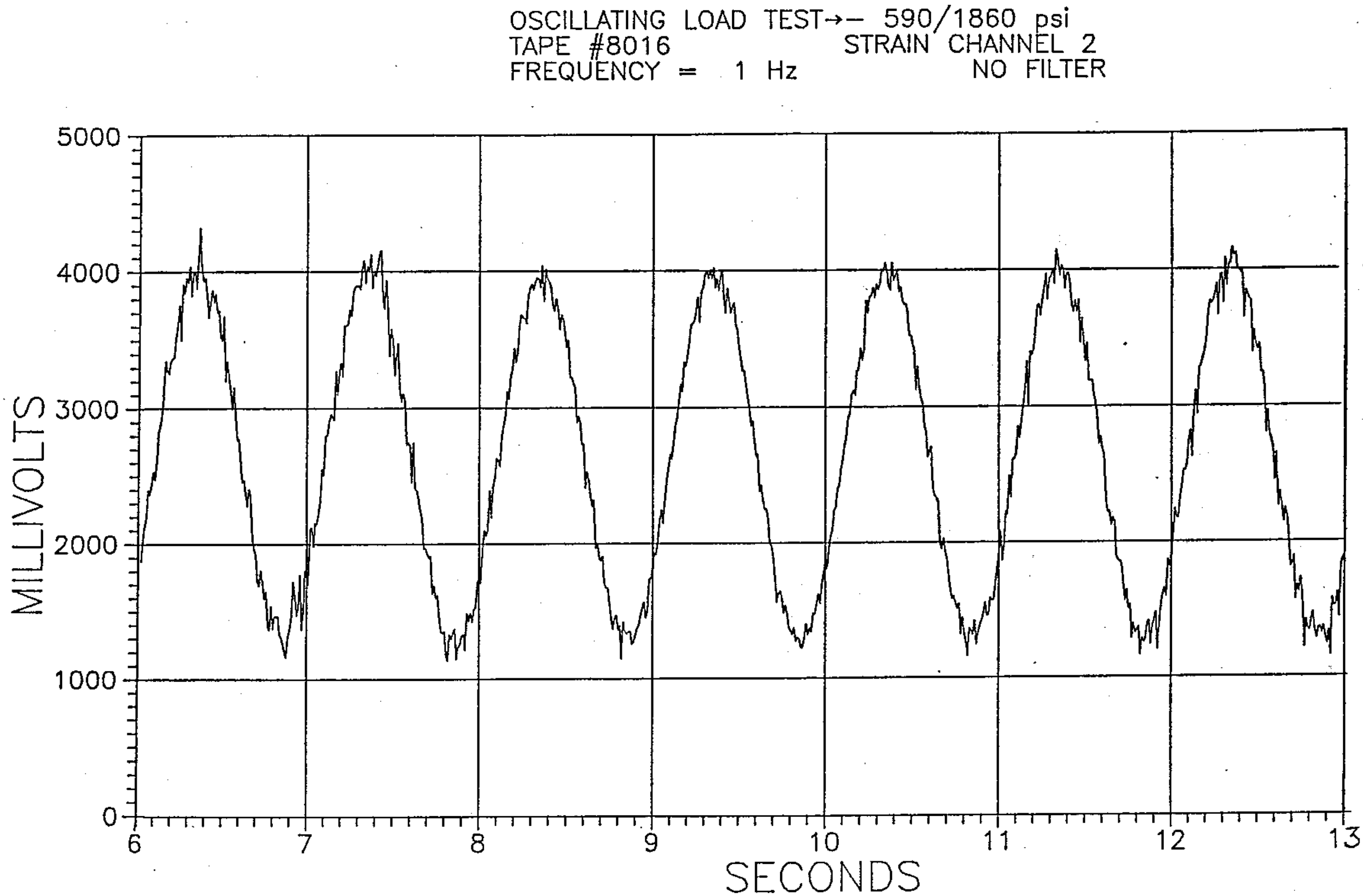


Figure 13. TEST WAVEFORM

The next step was to test the ability of the system to read the actual strain changes on the skin of the light standard pole near its base using a bonded strain gage (Figure 14A & B). To prove this technique, an existing Type 15 lighting standard at TransLab was instrumented with a spot-welded gage and wired to the test system. Under northwest wind conditions of 10 to 15 mph, the output was easily seen on an oscilloscope and the resulting data trace is shown in Figure 15. The strain values at this point at the base of the pole were determined to be smaller than the expected signal in the proposed bolt system. Therefore, this proved the method for measurements in the field. An actual test site installation was the next step to be undertaken.

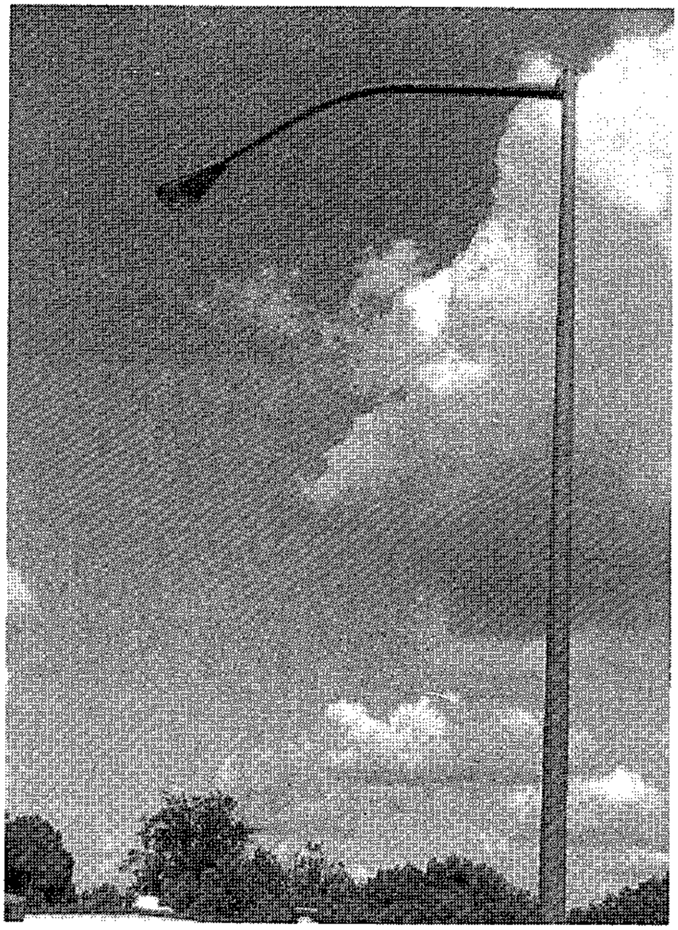


Figure 14A. PROTOTYPE LIGHTING STANDARD

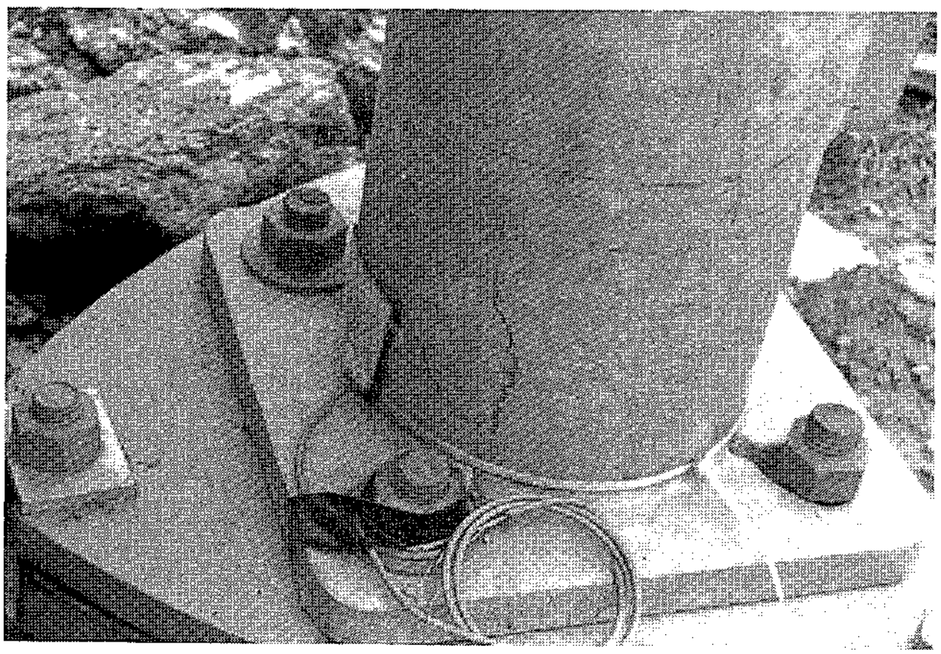


Figure 14B. PROTOTYPE POLE SURFACE GAUGE

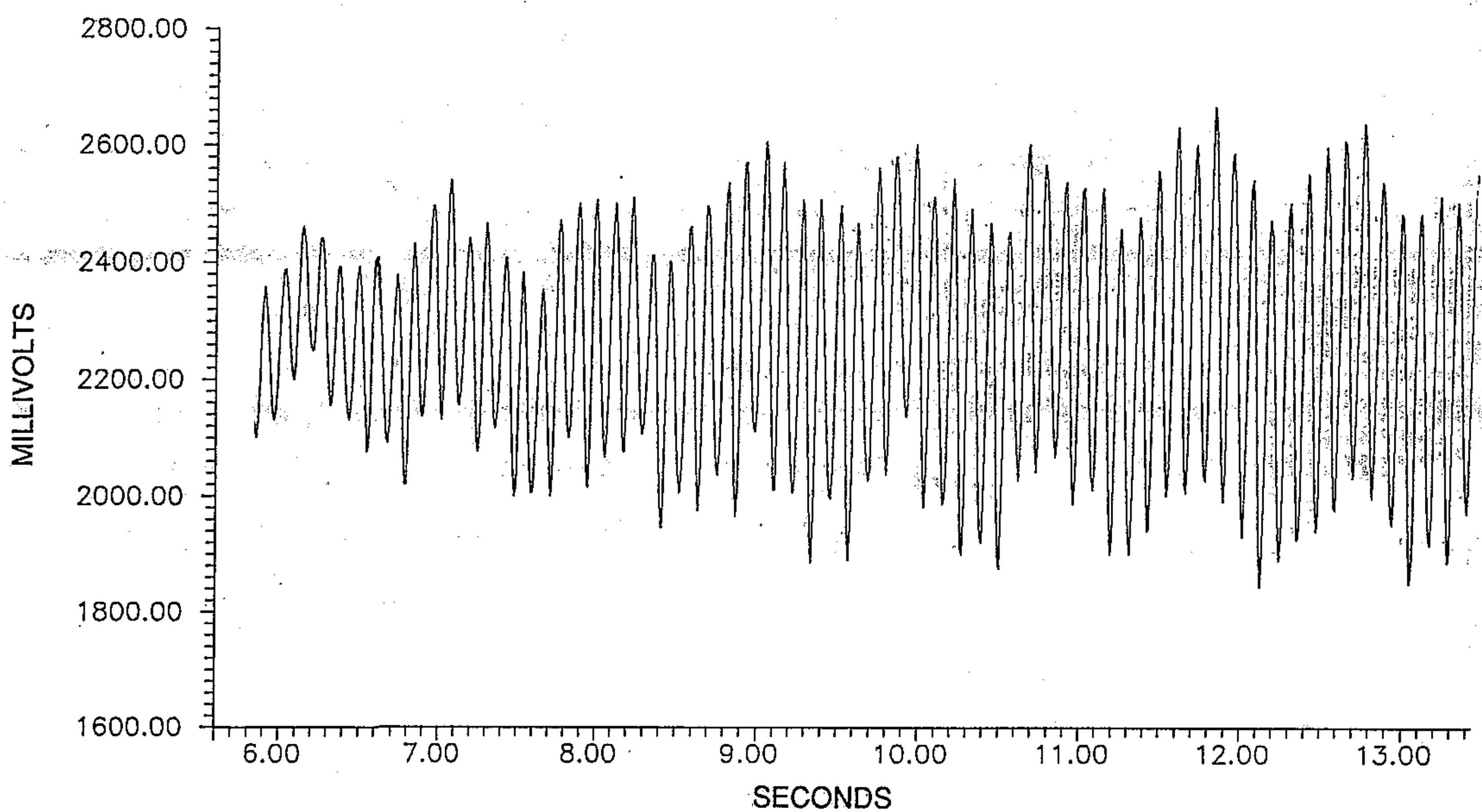


Figure 15. PROTOTYPE POLE SURFACE STRAIN WAVE FORM

12. TEST SITE SETUP AND EQUIPMENT INSTALLATION

The test site is located in a paved area of the parking lot for the Benicia Toll Bridge. There was some concern by the local Caltrans district maintenance personnel about the ground stability of the area where the pole was to be located. This area had experienced slippage in the past and an on-site building had been demolished because of ground movement damage. To address this issue, a site evaluation was provided by District 04 soils and materials engineering staff to determine if the excavation and resulting pole installation would cause a problem with the slope stability. The installation was approved by the geologist with the condition that the pole base was placed 27 feet from the slope edge.

The hole for the installation of the pole base was excavated by the TransLab drill crew with a bucket drill rig. The hole conforms to Caltrans July 1984 Standard Plans (ES-6D, page 217) for diameter (30 inches) and depth (60 inches). A plywood template held the instrumented anchor bolts in the specified spacing when placing the concrete. The anchor bolts were oriented so that the luminaire arm would be 160 degrees from north (perpendicular to the prevailing winds). Concrete was purchased from a small local plant and hauled in a trailer to the site and placed by TransLab employees. After a four-week curing time, the instrumented bolts were wired to the signal conditioning devices and the minicomputer.

To complete the documentation of the wind forces and resulting movement of the lighting, standard accelerometers were placed in the luminaire head. Accelerometers were installed in all three planes to document the X,Y,& Z components. The three accelerometers were mounted in the luminaire housing as close to the center of gravity as possible (Fig. 16). The mass of the accelerometers was very small incomparison to the overall

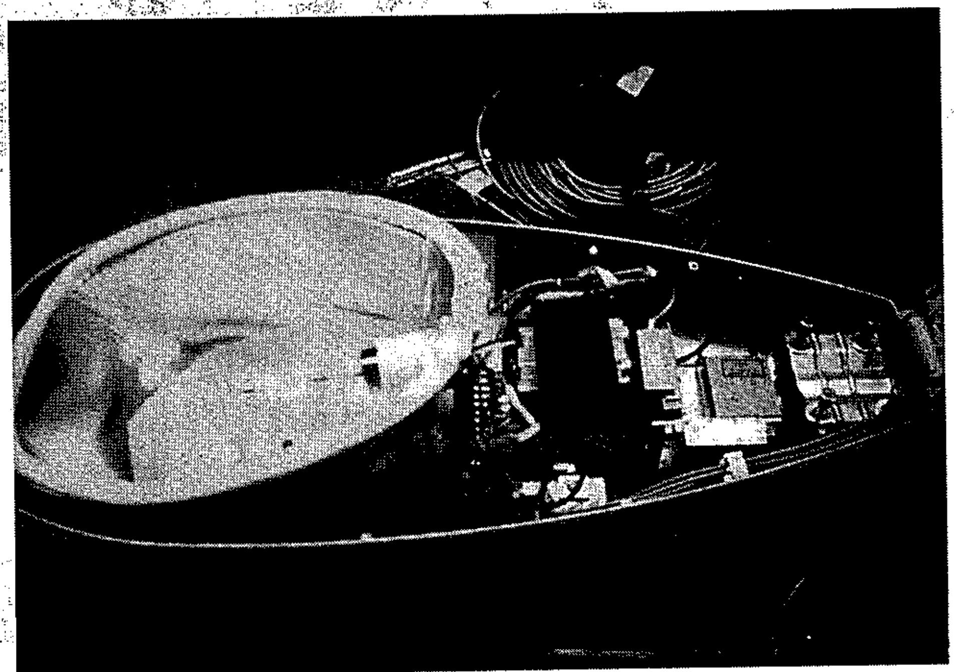


Figure 16. ACCELEROMETERS IN LUMINAIRE

luminaire mass. Therefore, the response of the assembly should be the same. The three units were bolted to the luminaire housing and wired to a terminal strip. Then it was determined, that due to physical positioning, the following would be true:

Looking at the pole from the luminaire, (Figure 17)

A1 the X plane - "+" is left
A2 the Y plane - "+" is down
A3 the Z plane - "+" is out from pole

The accelerometer cabling would be installed at the test site.

District 04 Maintenance was called about pole acquisition and installation. Mr. Warren Sanford, electrical foreman for Alameda maintenance, located a Type 31 pole (14-inch anchor bolt circle diameter) and 20-foot luminaire arm in the district surplus storage. He agreed to help with the test site installation and to dismantle it when the project was concluded.

During late January 1987, the district light standard maintenance crew installed the pole and arm on our concrete foundation and instrumented anchor bolts with minor problems. The mounting of the pole to the anchor bolts was difficult at best. This problem was amplified by the exposed leads and conductors protruding from the top of the anchor bolts (Figure 18). The maneuvering of the pole base around the anchor bolts with the strain gage leads extending from the bolt ends was a problem as the contacts for the wires are very fragile. The pole weighs approximately 240 pounds and when it is suspended vertically, with a 70-pound arm and a 40-pound luminaire attached, it becomes very awkward to align to the anchor bolts. The anchor bolt pattern fit to the pole base notches was very tight.

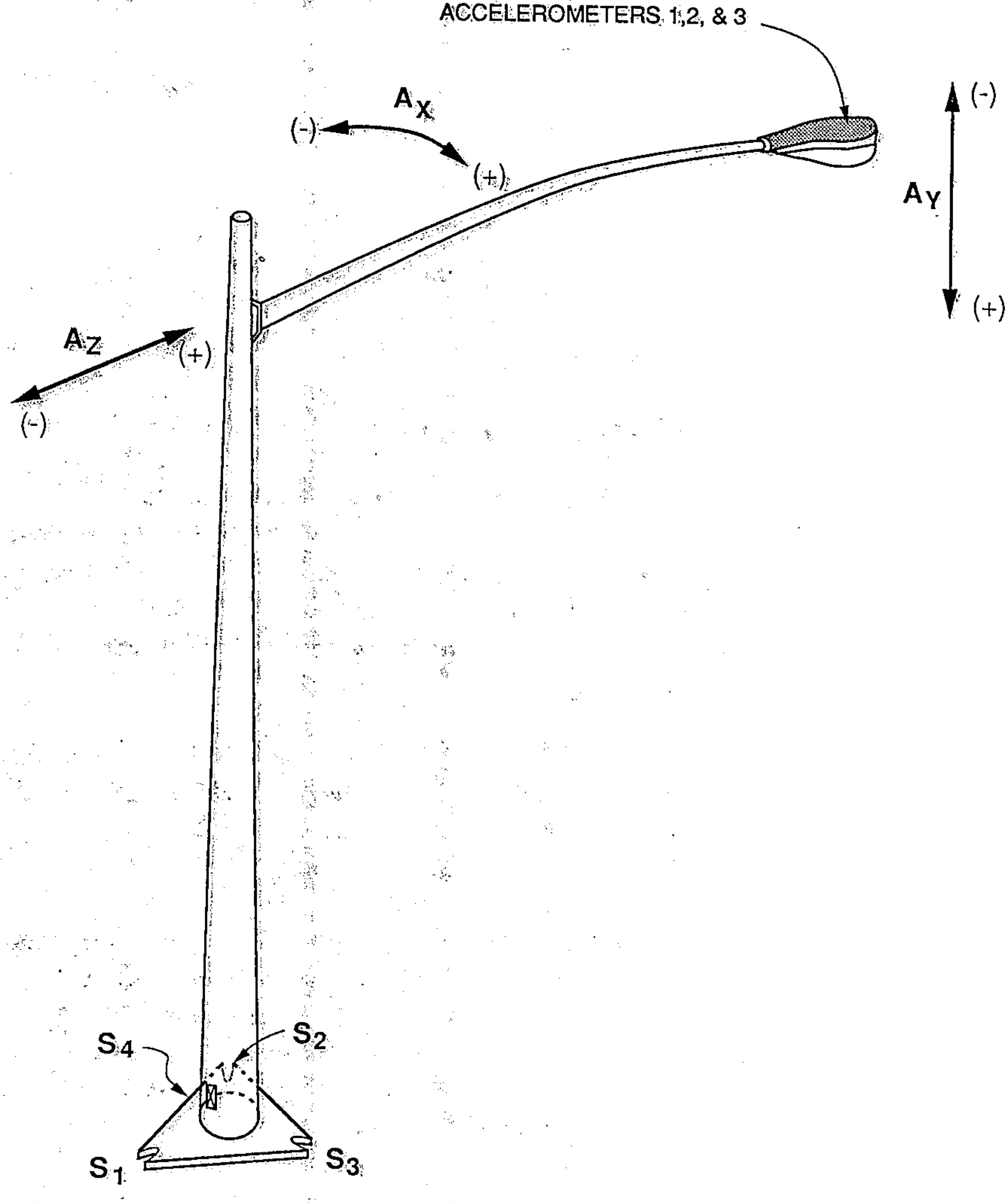


Figure 17. TEST POLE & SENSOR LOCATION

This caused the base plate to align to two of the anchor bolts but bind on the third. The pole was placed in final position when a maintenance worker, with good intentions, hit the third anchor bolt with a 10-pound sledge hammer and the base popped into place. This bolt was examined with care and seemed to suffer no adverse visual effects. When data from this instrumented bolt were reviewed no inconsistencies were detected. This seems to be standard practice in field installations of light standards - if it doesn't fit, hit it with a hammer!

The pole was leveled with the adjustment/leveling nuts and the top nuts were tightened until snug tight, approximately 100 foot-lb. No grouting was placed around the base to eliminate any bias of bolt loading.

It was necessary to rework several of the electrical contact tabs on the top of the bolts where the leads for the strain gages emerged. The leads were soldered directly to the tabs after straightening and tested for continuity. All gages survived the pole installation.

The accelerometer cables were installed as the arm and pole were assembled. The leads were continuous from the terminal strip in the luminaire housing, in the arm, and down the inside of the pole and out the access port at the base. From there, they were bundled together with the strain gage cables and routed to the instrument van some 50 feet away. The cables were routed through the drivers side window (lee side to the stormy weather) and the window taped shut.

Once inside, the cables ran directly to the signal amplifiers (Figure 19), one for each sensor. Since signal line shielding is very critical for low level signals and possible radio frequency (RF) interference, the cables were selected with continuous shielding that was grounded to the signal amplifier. The other

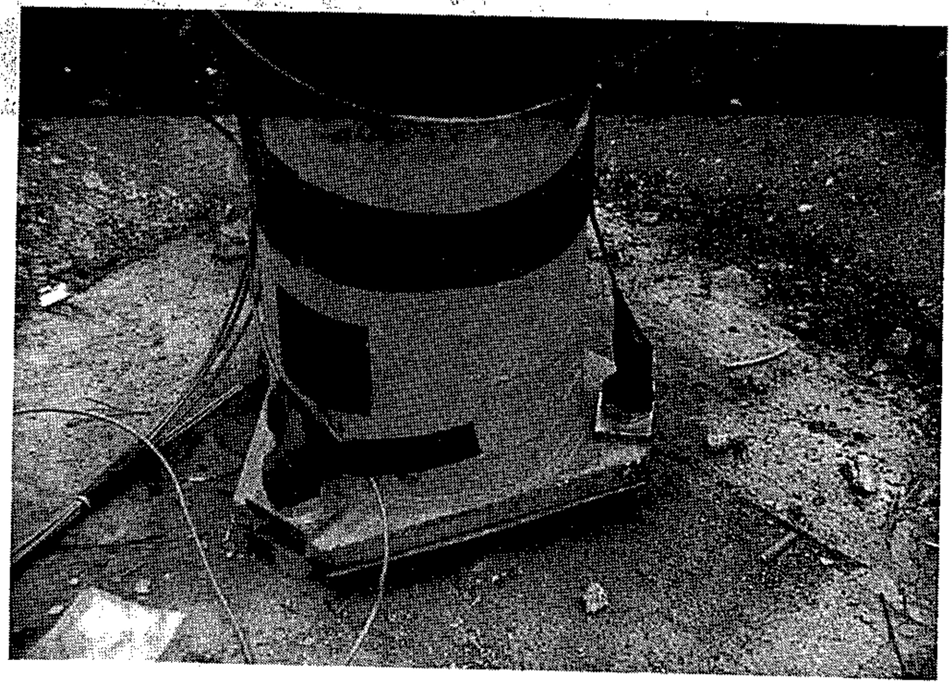


Figure 18. ANCHOR BOLTS AND STRAIN GAUGE WIRING

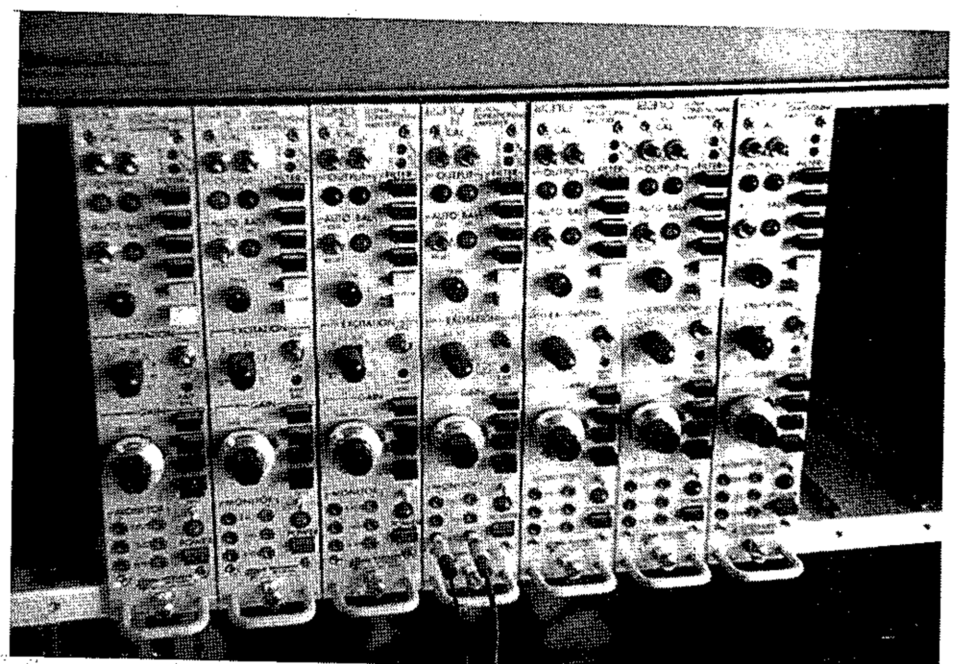


Figure 19. SIGNAL AMPLIFIERS

end of the shield was left floating to prevent ground loops that induce signal errors. See Figure 20 for the wiring schematic.

An additional strain gage was bonded to the pole approximately 4 inches above the base-plate weld, aligned with the back bolt opposite to the arm position (Figure 21). This gage provided a reading of change of strain produced on the pole skin as it was installed after the lighting standard assembly was raised. A zeroing for this gage was approximated when the arm length was changed from 20 to 30 feet. When the 20-foot arm was removed the strain gage saw the loading of the pole alone and this was adjusted on the signal amplifier to be approximately zero strain. When the 30-foot arm was installed the strain increase reflected the added tension load due to the moment created by the weight of the arm. These strain values are to be used as change in strain only.

Initial checkout involved zeroing the anchor bolt system in the unloaded state and a checkout of system background noise. The electrical signal generated with these sensors was very low and any RF noise picked up by the signal leads and amplifying components would possibly mask or modify the data signal. Particular care was taken with signal lead shielding and component grounding. Sensitivity of the system was determined to be 0.001 kip for bolt load readings, 2.5 uE for pole skin strain readings, and 0.001 g for luminaire accelerometer readings.

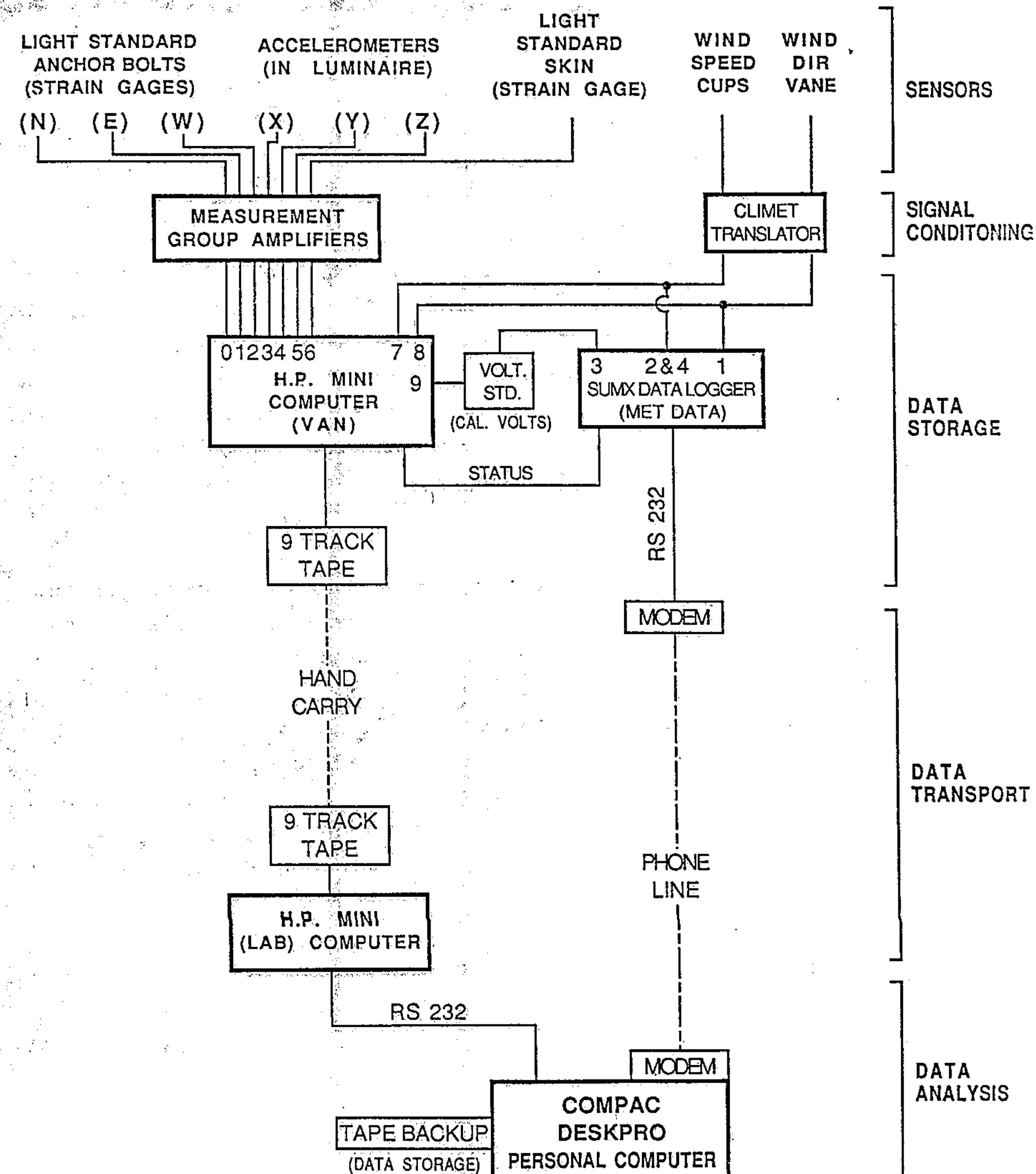


Figure 20. DATA SYSTEM DIAGRAM

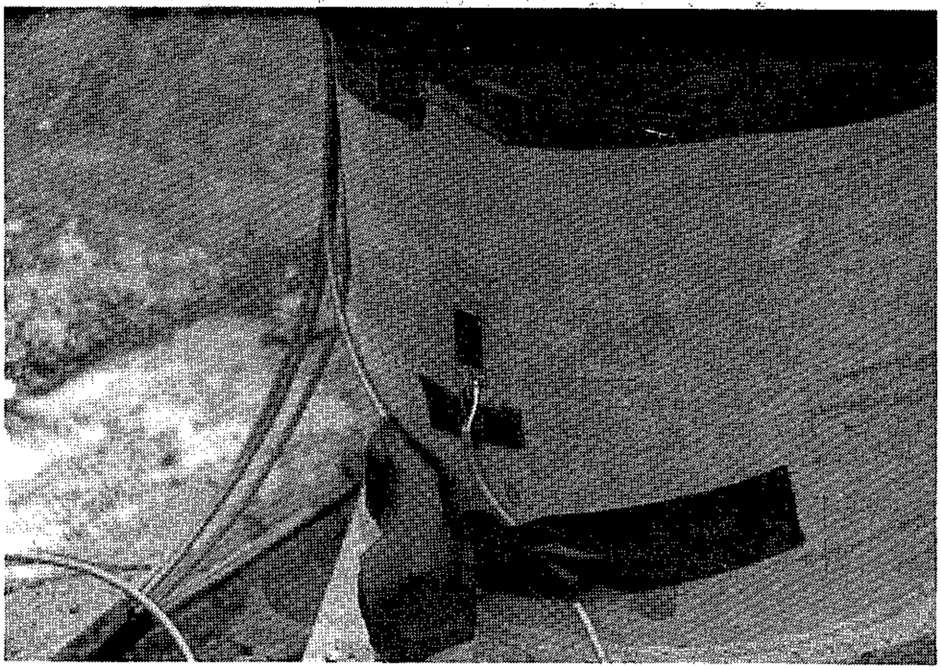


Figure 21. POLE STRAIN GAUGE

13. DATA ACQUISITION

Initial parameters entered during on-site program start-up were tape number (80XX), Julian date (1XX), location code (04680), time (00,00), and wind speed to start (05,10,15,...etc.). The speed entered was the level to initiate data recording and the program was written to take data for a minimum of one minute before shutting down for a lower wind speed. This allowed us to take one minute blocks of data without instantaneous spikes or clipped data. Initially there was an operator selected maximum wind speed which would halt the data taking process, but this was eliminated due to the chopped effect it had on the recorded data. The direction was restricted to a window of (+) (-) 20 degrees from perpendicular to the arm (northeast-east or southwest-west) with computer software. In the winter months the wind varies from 65 to 80 degrees and from April through October from 240 to 260 degrees (Figure 22 & 23).

The wind speed and direction sensors sent a signal to the meteorological translator (signal conditioning) box which converted the sensor signal to a linear voltage compatible with the SumX data logger and the HP computer. During the HP computer operation, this signal was reviewed for an acceptable level so that the data recording process could be initiated. To direct the data acquisition to specific conditions, the above limits were imposed. Ideal conditions would be wind perpendicular to the arm at specific constant speeds.

When sampling complex, periodic waveforms, there are some important aspects to consider for minimum sampling rates to define their shape. If the waveform is assumed to be sinusoidal, scientists Nyquist and Shannon (3) determined that there must be at least two equally spaced samples per cycle to determine the periodicity of a periodic waveform. "To apply this sinusoidal analysis to a complex wave which is comprised of individual

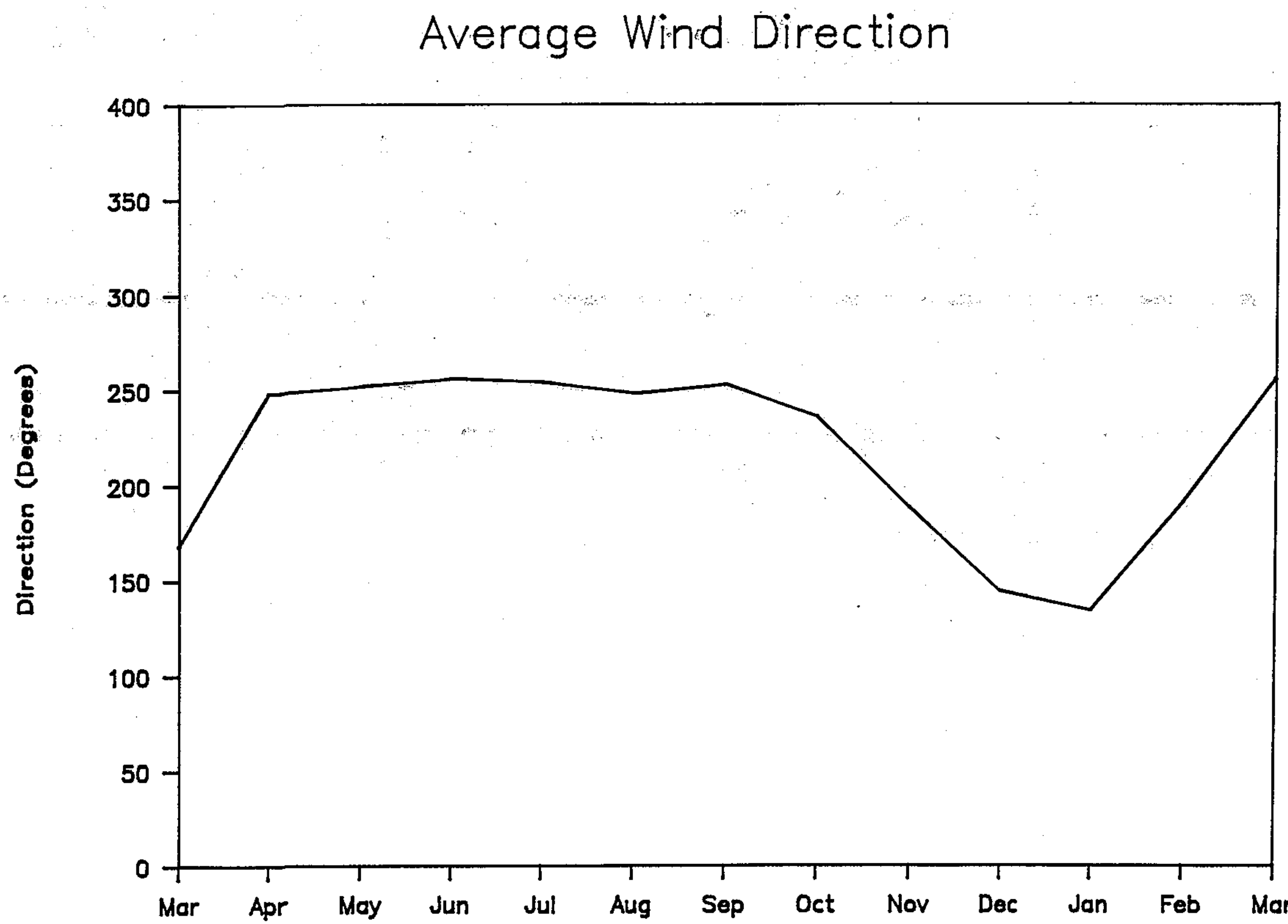


Figure 22. PREVAILING WIND DIRECTION vs MONTH

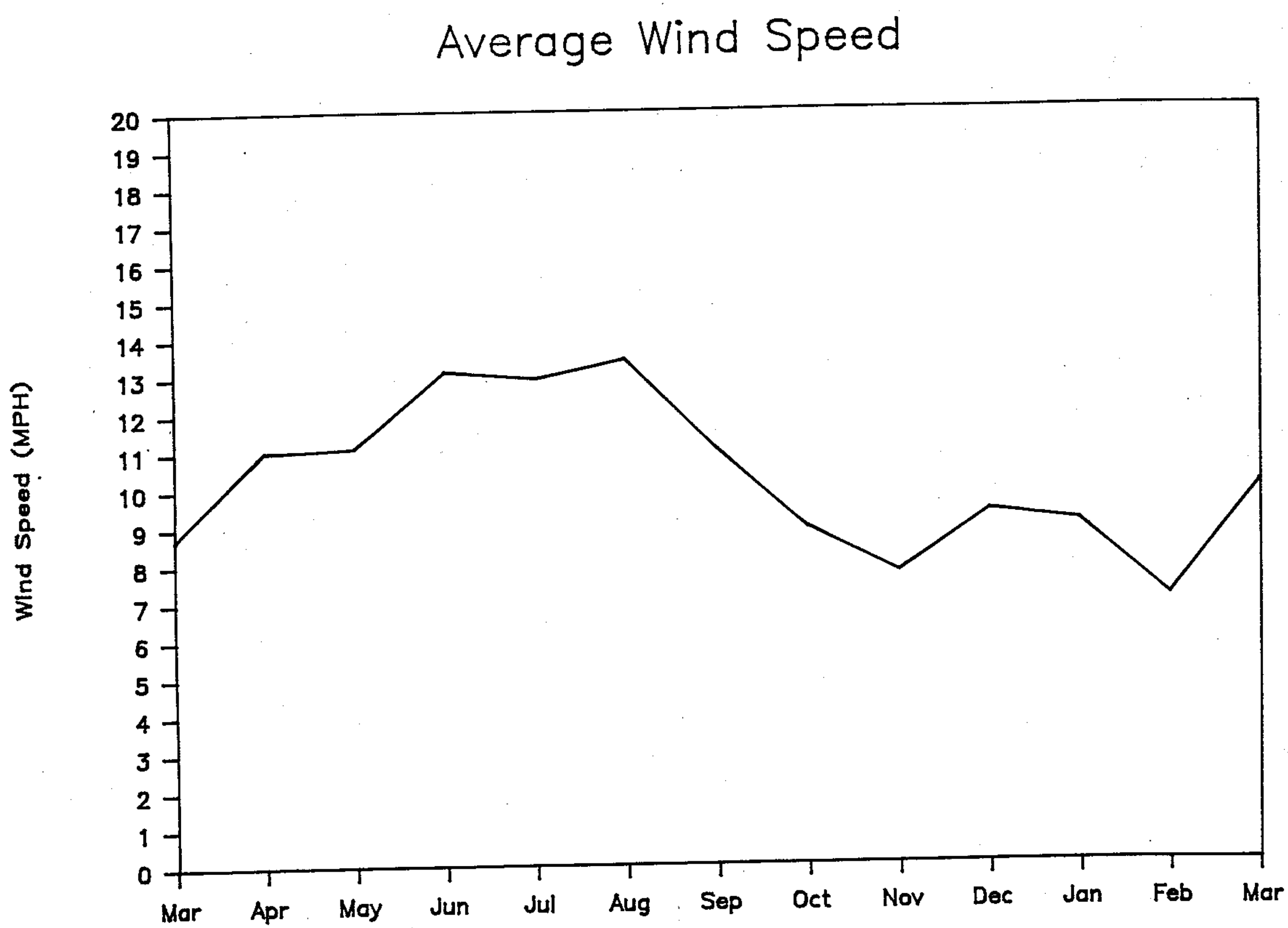


Figure 23. AVERAGE WIND SPEED vs MONTH

sinusoids, it is sufficient to consider the sampling rate effects on the highest frequency sine wave component which makes up the complex waveform" (3). Considering this guideline and the test data taken on the prototype pole at TransLab, the parameters were sampled at varying rates. The bolt loading data was taken at 100 readings per second. The acceleration data were taken at 500 readings per second. The wind speed and direction readings were obtained at 20 readings per second. These sampling rates were a compromise between number of readings required to accurately define the waveform and the abilities of the computer to acquire and store the data. By sampling at these rates, the possibility of aliasing (error in measuring frequency and peaks and valleys in fatigue analysis) is greatly reduced.

Using Donaldson's definition of error in peak levels of sampled waveforms (3) we have maintained a potential error limit of 5 percent and a data record length of approximately 1 hour.

When reading 3 bolt loads, 1 surface strain gage, 3 accelerometers, 1 wind speed, and 1 wind direction, the 2400-foot magnetic tape on the HP computer tape drive lasted approximately 58 minutes. The program was written to signal a switch closure to the SumX data logger when the tape ran out or if the computer shut down. As stated previously, this appeared as a "B" flag after the voltage column in the SumX summary display. The SumX data logger was accessed by telephone lines and a modem so that its status could be monitored at TransLab. In addition, the data taken by the SumX system on cassette tape could be downloaded to the printer, or the disk drive, at TransLab. This reduced travel to the test site and person time to a minimum.

14. DATA REDUCTION

The first stage of data reduction consisted of converting the data storage medium from HP 9 track magnetic tape to data files on the Compaq PC hard drive. Software was written for the HP Model 2114 computer in the Air Quality Lab to read the HP 9-track magnetic data tapes taken in the field and process the data through a hard wire connection to the Compaq PC. The 30-megabyte hard disk was segmented into three artificial drives, C, D & E, with the E section dedicated to this data storage. A backup data tape was recorded on a mini-cassette (3M 100 series) on the Compaq PC tape system.

All data taken for the Benicia test site were screened first by examining the minimum and maximum readings in each data block. These readings were printed on a graphic representation versus time (Figure 24). This allowed visual inspection of the analog trace to determine if there were system problems which would produce inaccurate data.

When analyzing vibration data for fatigue occurrence, it has been determined that fatigue is not dependent on average amplitude, but upon the peak amplitudes and the sequence of peak stress amplitudes which a component experiences. Therefore, it is important to record an accurate measure of each peak and valley as well as the sequence of the peaks and valleys in the data set (3).

Each data set consisted of corresponding values of bolt loadings S1, S2, & S3; accelerations Ax, Ay,& Az; pole base surface strain S4, wind direction W/D, and wind speed W/S, and time. These were divided into 12-second data blocks. Minimum, maximum, average values and the standard deviation (SD) were recorded for each parameter. This data was recorded in Lotus 1,2,3 data files on 5 1/4-inch floppy disks. This format allows many data manipulations and graphical plotting.

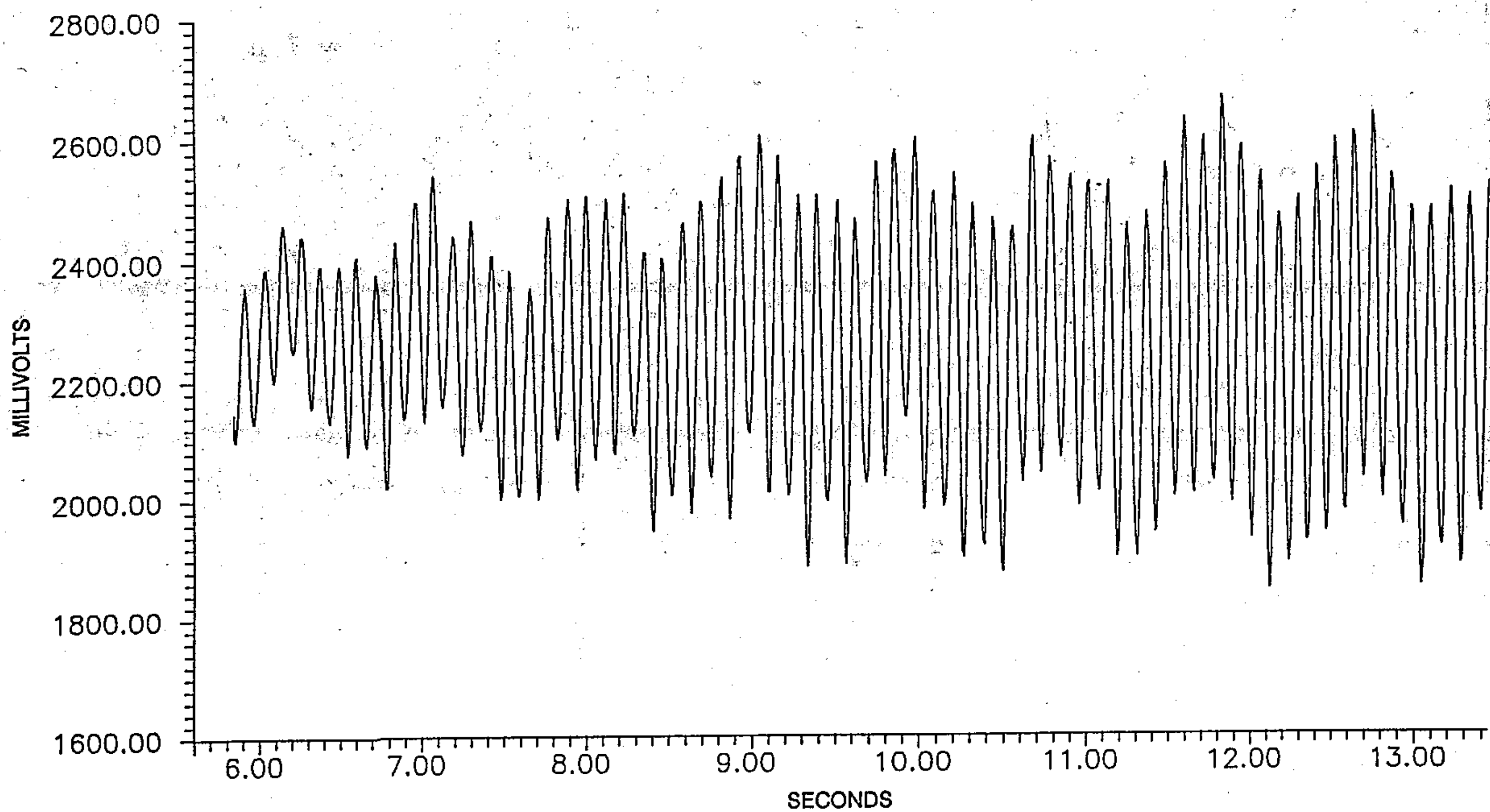


Figure 24. MINIMUM/MAXIMUM DATA vs TIME

In addition, software was written to convert the raw data files to a format that would be compatible with the commercial data processing program, ASYSTANT. This program performs fast Fourier transformations (FFT) on the loading and acceleration data to determine the natural frequency and other harmonics for the structure. See section 15.6.

15. ANALYSIS AND RESULTS

15.1 Meteorological Data

The meteorological conditions encountered for the period February 1, 1987 to February 29, 1988 were not typical for the area. The California weather patterns for these two winter seasons were abnormally dry with few storm front passages. Wind direction was steady from April through September at 250 (+) or (-) 10 degrees. Peak average winds occurred during July and August, with the high average of 13.6 mph. The expected storm-generated peak winds did not occur, but wind gusts over 44 mph were documented. On occasion, winds did occur which could have been higher than those measured, but either the direction was outside the necessary conditions or electrical power outages prevented data collection.

Wind gustiness is shown by the standard deviation of the wind speed. For the test location the higher SD's occurred during wind speeds of 20 to 25 mph and trended lower at higher speeds.

15.2 Wind Forces

Wind loading on structures is divided into two types: along wind forces and across wind forces. The along wind forces are dependent on wind speed, wind direction, air density, and shape and the area of the object on which the wind acts. Therefore, the wind force is:

$$P = CAq$$

$$Q = (1/2)\rho V^2$$

where C = shape factor
A = area acted on
Q = wind dynamic head
P = wind force
ρ = air density
V = air velocity

An additional correction factor, CH, coefficient of height above the ground to the centroid of member the air acts on, should be considered. This reflects the changes in wind speed near the ground as shown previously in Figure 7.

This reduces to: $P = 0.00256(1.3v)CC_D$, as noted in AASHTO specifications (5).

C_D= drag factor

The wind measurements for this research were taken at the approximate height of the arm (35 feet from ground surface) where the most significant wind forces occur for this structure.

The shape factor is broken down into two components, the along wind drag factor C_D and the across wind lift factor C_K. These values for the object shape have been determined experimentally in a wind tunnel for different wind speeds (Fig. 25). They vary with the Reynolds number (Re), an index of the flow characteristics expected to occur, of the wind flow over the cross-sectional shape.

$RE = \rho Vd/u$ where ρ = air density

V = air velocity

d = shape characteristic (diameter)

u = air dynamic viscosity

Re = Reynolds number

This reduces down to $Re = 778.4\ Vd$ when using standard air conditions, velocity in miles per hour, and pole and arm diameters are in inches. This is important because the Type 31 pole and arm are constructed with a tapering cross section (changing diameter) versus length. Therefore, the Reynolds number is changing with wind speed and with pole height and distance out on the arm. For example:

Reynolds Number *

Member	Base	Tip
Type 31 pole	1.9×10^5	3.4×10^5
20 foot arm	7.4×10^4	1.6×10^5
30 foot arm	7.4×10^4	2.0×10^5

* Wind Speed = 40 mph

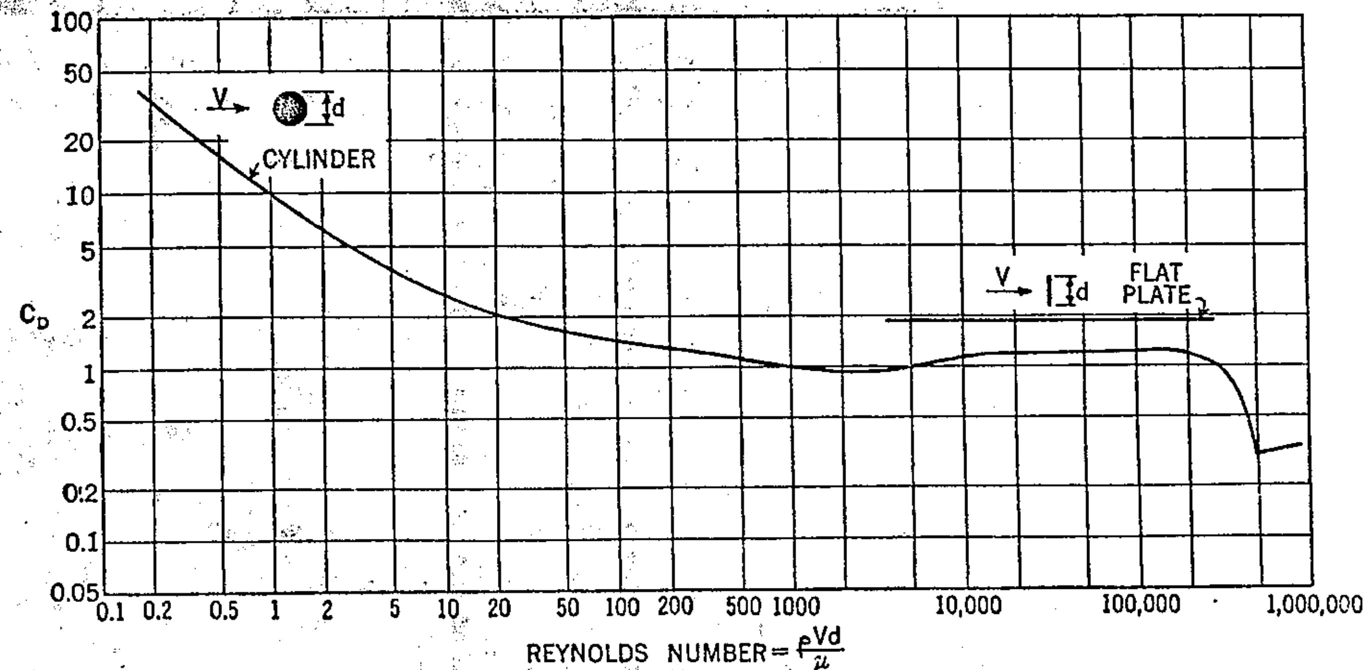
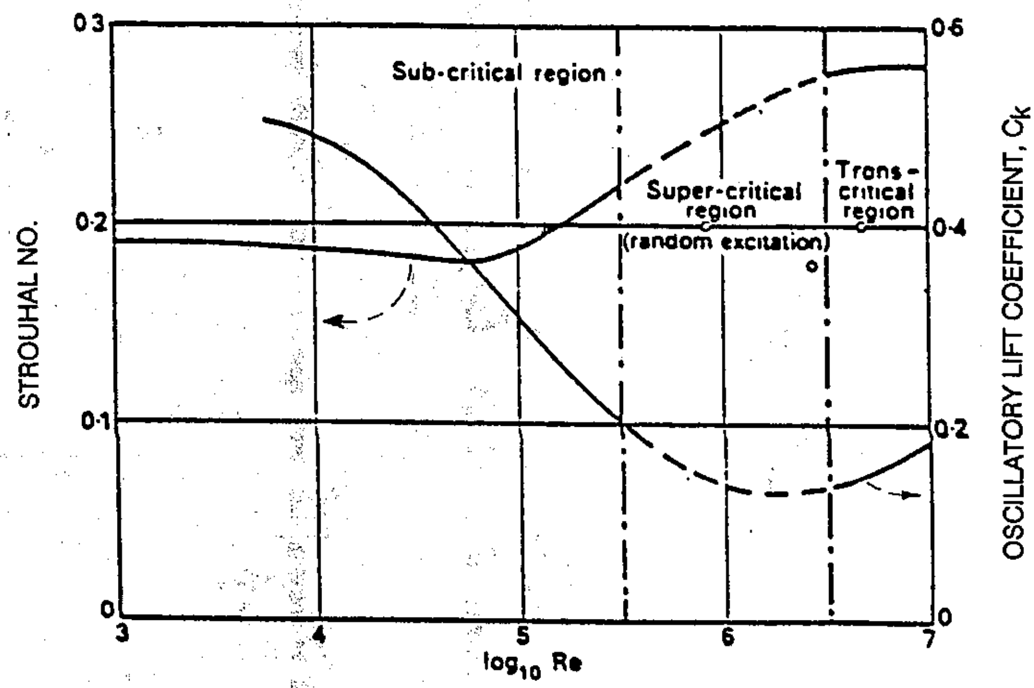


Figure 25. C_d vs REYNOLDS NUMBER (16)



FOR A CIRCULAR CYLINDER, DERIVED FROM WIND-TUNNEL TESTS

Figure 26. STROUHAL NUMBER vs LOG Re (15)

15.3 Vortex Shedding

Winds generate forces other than those which are parallel to the wind direction. One of these forces is dependent on vortex shedding, a phenomenon which occurs when the wind separates on each side of the structural shape and eddies or vortices are formed. These vortices separate in a fluctuating pattern which induces a suction force on alternating sides of the structure perpendicular to the wind direction. This force is generated only when the wind velocity is constant and unidirectional and can be calculated by using the following:

$$F = (1/2)\rho V^2 C_k A(\text{Sin } W_n t) \qquad (15)$$

C_k = lift coefficient
W_n = frequency of vortex shedding radians/sec.
t = time in seconds
F = force perpendicular to member
A = area acted on
V = air velocity
ρ = air density

The air flow which causes this vibration is highly dependent on the Reynolds number, the angle of the wind to the structure, and the shape of the structure member. This phenomenon occurs between Reynolds numbers of 300 and 300,000, but the higher the number, the more likely the forces are random (11).

15.4 Strouhal Number

The vortex shedding phenomenon was first reported by Strouhal, who described it with the nondimensional equation:

$$S = f_v D/V;$$

where f_v = frequency of full cycles of vortex shedding, (Hz)
D = dimension of the cross section normal to the flow (ft)
V = wind velocity (assumed laminar, ft/sec)
S = Strouhal number

Checking the pole and arm dimensions and the range of wind speeds of interest, it is apparent that the Strouhal number equals 0.18 to 0.20 (15). For flow around a cylinder, the Strouhal number for Reynolds number above 10^5 varies significantly, so designers should take this into account (Figure 26).

Previous research has shown that the maximum response from vortex shedding occurred when its frequency was the same as one of the lowest natural frequencies of the structure. When $f_v = f_n$, a resonant condition occurs.

It is of interest that the Strouhal number varies with the shape of the component the wind flows around. In the case of the lighting standard arm, as the wind changes angle to the arm, the shape of the arm becomes an apparent ellipse with a changing axis dimension. This has a definite effect on the drag forces and the vortex shedding forces.

15.5 Critical Wind Velocity

If one equates the frequency of vortex shedding to f_n and solves for V_c, this will give the critical wind velocity for structure vibration, where maximum displacement will occur:

$$V_c = f_n D/S = \text{"critical" velocity.}$$

For tapered elements there is debate about the appropriate diameter to use. Some authors have recommended the diameter at the tip of the tapered section, where others have recommended a calculated equivalent diameter or average diameter. For this study the equivalent diameter and equivalent lengths, as noted in AASHTO guidelines, are used.

Therefore, $V_c = 1.02(0.7)/0.18 = 3.97$ ft/sec or 2.7 mph

This is the critical wind velocity for the Type 31 pole alone, based on the lowest natural frequency. The critical velocity for the 20-foot arm is 1.3 mph and for the 30-foot arm it is 0.88 mph. These are theoretical values and the critical velocity for the composite structure can be determined using the lowest natural frequency determined by Fast Fourie Transform (FFT) (See Section 15.6) from the field data for the pole and the arm as an assembly.

$$V_c = 0.78(.53)/0.18 = 2.3 \text{ ft/sec or } 1.6 \text{ mph}$$

The wind loadings at these speeds are very low and vortex shedding forces are not discernible in the field data. With all the variables involved in the analysis of the Type 31 lighting standard, varying wind speed, tapered structure members, and varying wind direction, there is not a high probability of observing significant changes in anchor bolt loading due to vortex shedding.

Above a Reynolds number of 10^5 the flow becomes turbulent and vortex shedding becomes random in nature. This causes the structure to oscillate at lower amplitudes (this appears as flutter in the member). This Reynolds number equates to 34.3 mph for the 20-foot arm, 28.9 mph for the 30-foot arm, and 21.8 mph for the Type 31 pole. At a Reynolds number of 3.5×10^5 alternate vortex shedding stops and the wake becomes aperiodic (3). This equates to 120 mph for the 20-foot arm, 101.2 mph for the 30-foot arm, and 76.3 mph for the Type 31 pole. A significant amount of data was collected at the field site for wind speeds up to 35 mph for both arm configurations. This should encompass the situations where vortex shedding would be a meaningful part of the wind forces.

TABLE V

CALCULATED NATURAL FREQUENCIES

Pole Type	Member	Natural Freq.	Crit. Velocity
31	Pole	1.02 Hz	2.7 mph
	20' arm	1.12 Hz	1.3 mph
	30' arm	0.63 Hz	0.88 mph

Natural Frequencies Determined From Field Data by FFT

Pole Type	Member	Natural Freq.	2nd Har.	3rd Har.	4th Har.
31	Pole/20'arm	1.07 Hz	2.44 Hz	8.64 Hz	12.96 Hz
	Pole/30'arm	0.78 Hz	1.80 Hz	5.37 Hz	10.27 Hz

TABLE VI

RANGE OF ACCELERATIONS & BACK BOLT LOADING

Pole Type/Arm	Max W/S*	A_x Range (g's)	A_y Range (g's)	S_1** (kips)
31/20	43.7 mph	+3.1/-3.5	+1.2/1.4	+0.58/+5.18
31/30	38.4 mph	+2.2/-2.1	+0.5-1.3	+3.02/+6.70

* Peak wind speed within a window of +/- 10 degrees perpendicular to arm.

** S_1 is the back bolt, away from the luminaire arm (See Figure 17).

TABLE VII

BOLT S_1 STRESS

Based on a bolt thread area of 0.606 inches for a 1"-diameter bolt with coarse threads.

Pole Type/Arm	Max W/S	Measured Bolt Stress	Calculated Bolt Stress	Measured Stress Range
31/20	44 mph	8548 psi	9540 psi	7590 psi
31/30	38 mph	11056 psi	13554 psi	6072 psi

The bolt stress was calculated using the IBM mainframe computer program "Traffic Signal & Lighting Standard Stress Analysis" (17), provided by Caltrans Structures Division. These values compare favorably with the measured values and are on the conservative side.

Relating the stress ranges to the fatigue cycle diagram (Fig 27), it is clearly shown that the bolt stresses, for the wind conditions experienced, are well below the stress range to cycles to failure curve out to a life over $2x10^6$ cycles. With the fact that maximum bolt stress does not exceed this value even once, the question of cumulative fatigue for winds up to 40 mph is not relevant.

To project what wind speed might produce, a stress range (greater than 10 ksi) which would cross over the fatigue curve, the top 10 percent of the maximum and minimum S1 loads were used to develop two diverging lines by regression analysis (Figure 28). Where these two lines differed by a load equivalent to 10 ksi for the bolt, is the beginning wind speed where fatigue damage may occur. That speed is approximately 50 mph for the Type 31 with 20 arm, and approximately 60 mph for the Type 31, with 30 arm lighting standard.

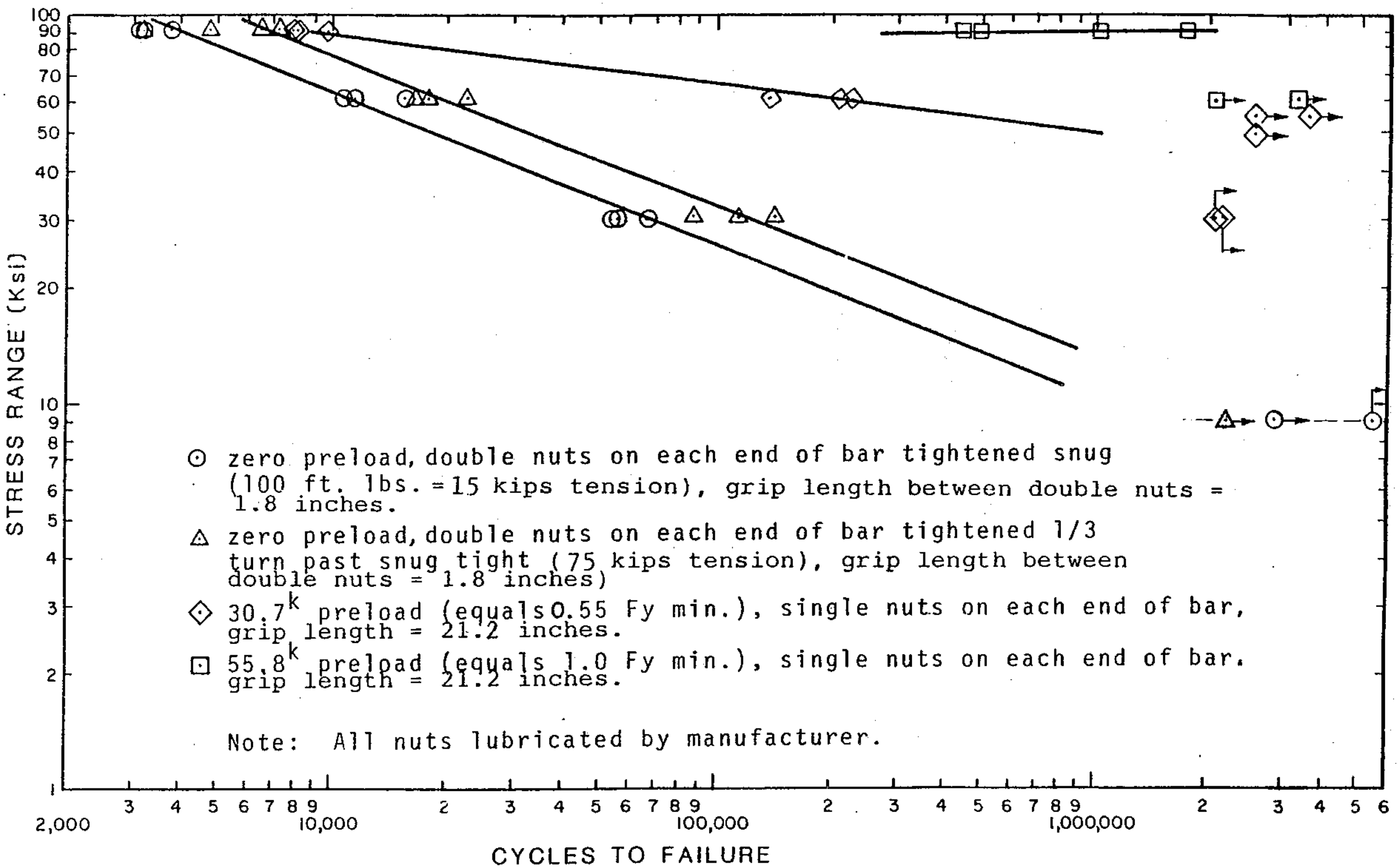


Figure 27. ANCHOR BOLTS FATIGUE LIFE CURVES

15.6 Fast Fourier Transform (FFT)

A program was developed to convert the raw bolt loading and luminaire acceleration data to a format that could be accepted by the commercial scientific program ASYSTANT. This PC software provides many mathematical and graphical processes and options. The main usage in this project was Fast Fourier Transform to generate the power spectrum representing the data frequency. FFT uses Fourier techniques to digitally process analog input signals with an algorithm that determines the Fourier coefficients and generates a graphical display of the spectrum. More simply, it converts a time-domain signal into a representation of the signal in the frequency domain. In this study it is used to interpret the natural frequency of the lighting standard structure and the related harmonics (Table VII). As the wind speed increases 41 additional harmonics appear in the FFT results, these are still well under the Niquist frequency as determined by the sampling rate.

TABLE VIII

20' ARM FFT POWER SPECTRUM (Hz) VS. WIND SPEED

W/S	Natural Freq.	2nd Harm.	3rd Harm.	4th Harm.	5th Harm.
37 mph	1.07 Hz	2.44 Hz	8.61 Hz	12.94 Hz	-
26 mph	1.07 Hz	2.44 Hz	8.64 Hz	12.99 Hz	-
20 mph	1.07 Hz	2.46 Hz	8.67 Hz	12.96 Hz	-
17 mph	1.07 Hz	2.44 Hz	8.63 Hz	12.94 Hz	-
10 mph	1.07 Hz	2.47 Hz	8.69 Hz	-	-

30' Arm FFT Power Spectrum (Hz)

25 mph	0.78 Hz	1.80 Hz	5.37 Hz	10.27 Hz	15.87 Hz

15.7 Data Plots

The following figures are presented as general information for the reader with a brief description:

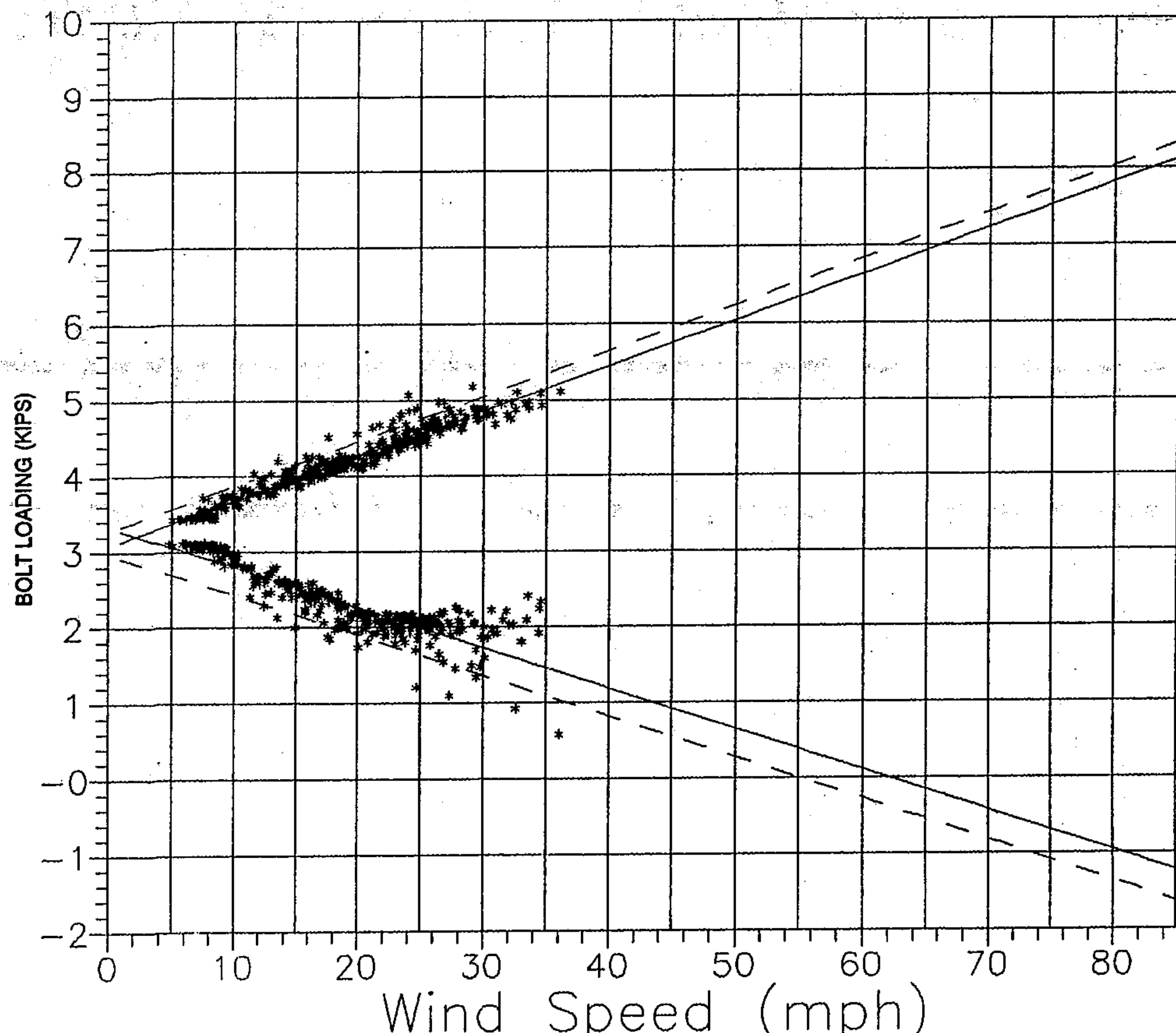


Figure 28. PROJECTED S1 RANGE vs WIND SPEED

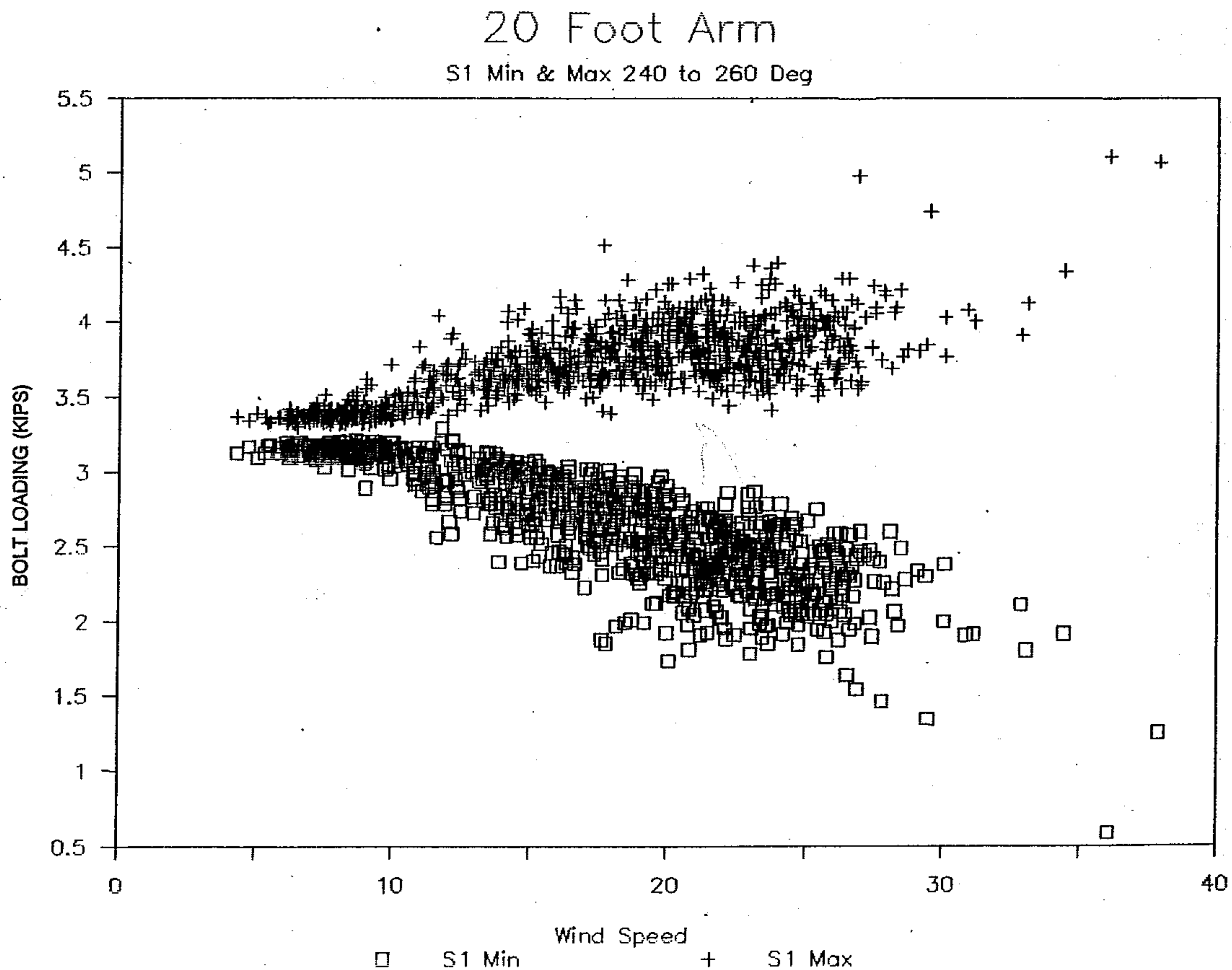


Figure 29. TYPE 31/20 - S1 MINIMUM AND MAXIMUM FOR WIND FROM 240 TO 260 DEGREES

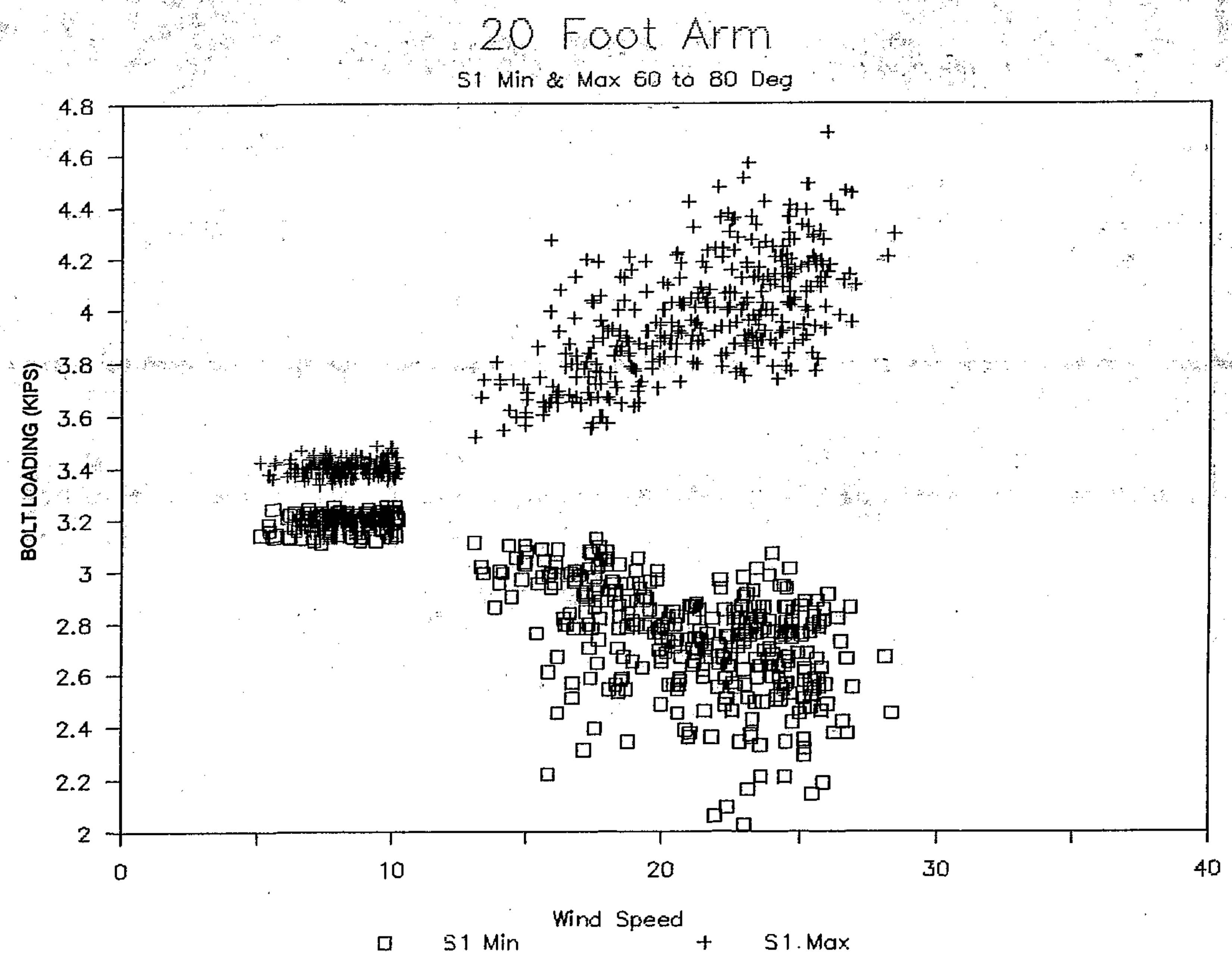


Figure 30. TYPE 31/20 - S1 MINIMUM AND MAXIMUM FOR WIND FROM 60 TO 80 DEGREES

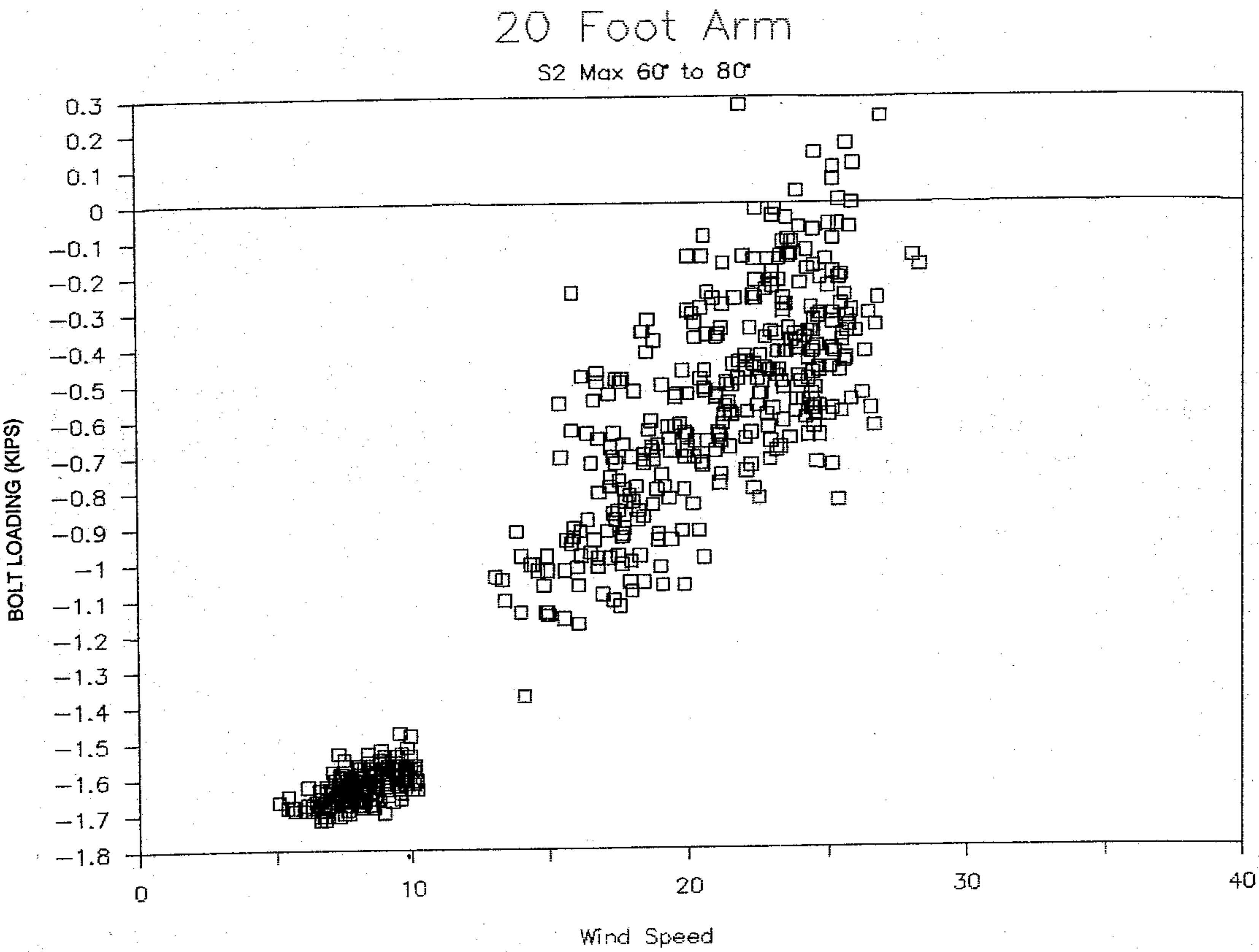


Figure 31. TYPE 31/20 - S2 FOR WIND FROM 60 TO 80 DEGREES (LOADING FROM THE EAST AND TOWARD THE S2 BOLT)

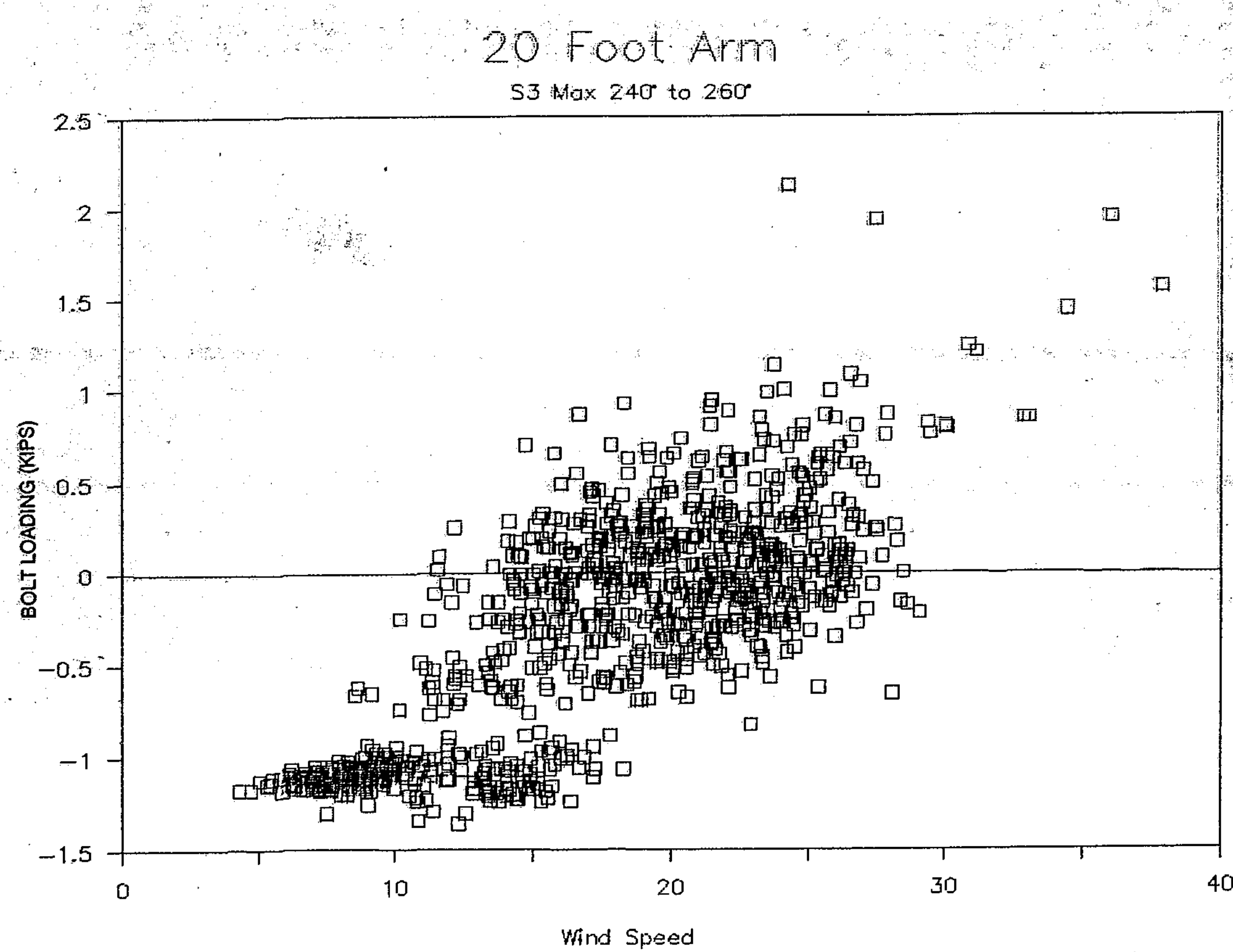


Figure 32. TYPE 31/20 - S3 FOR WIND FROM 240 TO 260 DEGREES (LOADING FROM THE WEST AND TOWARD THE S3 BOLT)

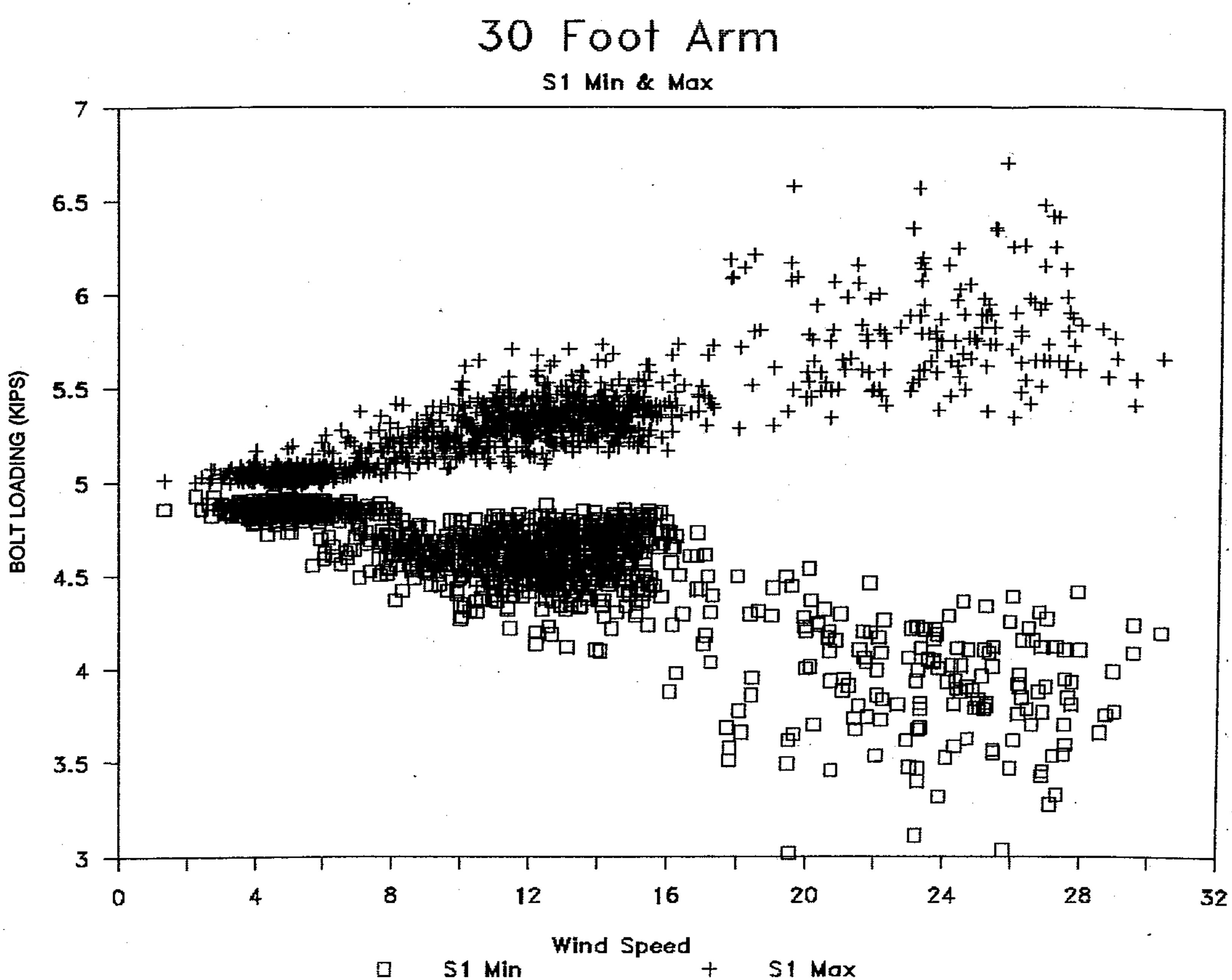


Figure 33. TYPE 31/30 - S1 MINIMUM AND MAXIMUM

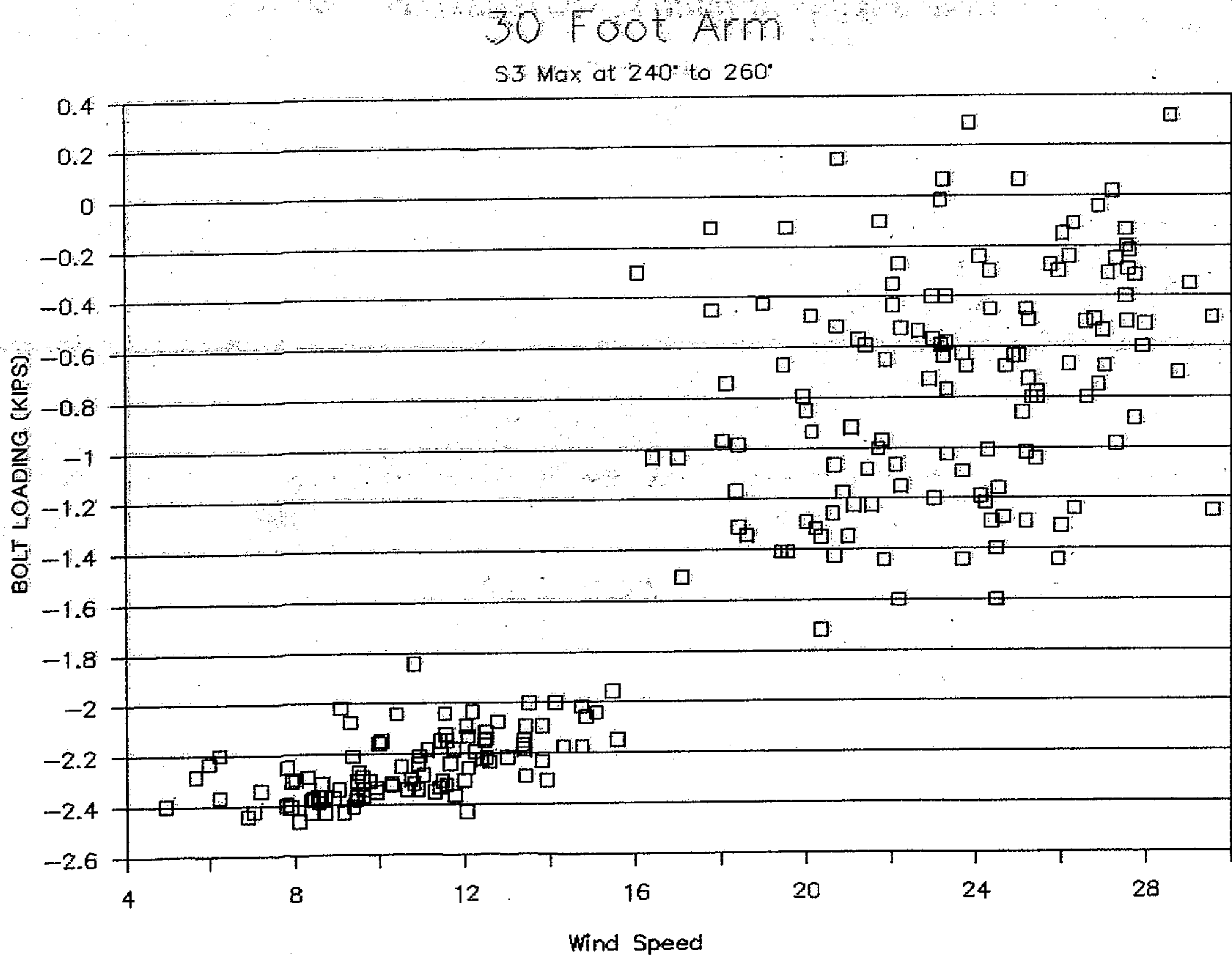


Figure 34. TYPE 31/30 - S3 FOR WIND FROM 240 TO 260 DEGREES

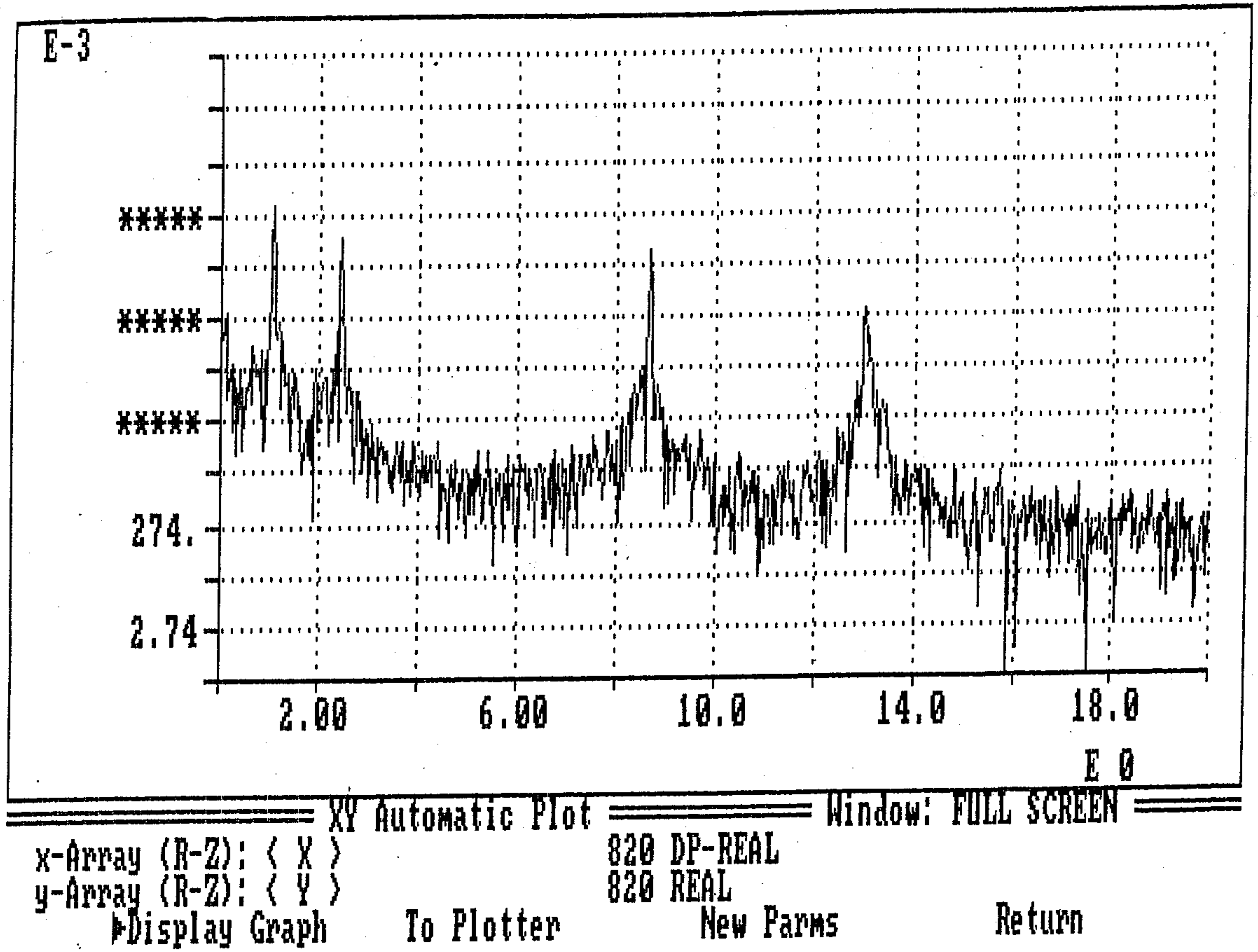


Figure 35. TYPE 31/30 - FFT SHOWS A POWER CURVE vs FREQUENCY

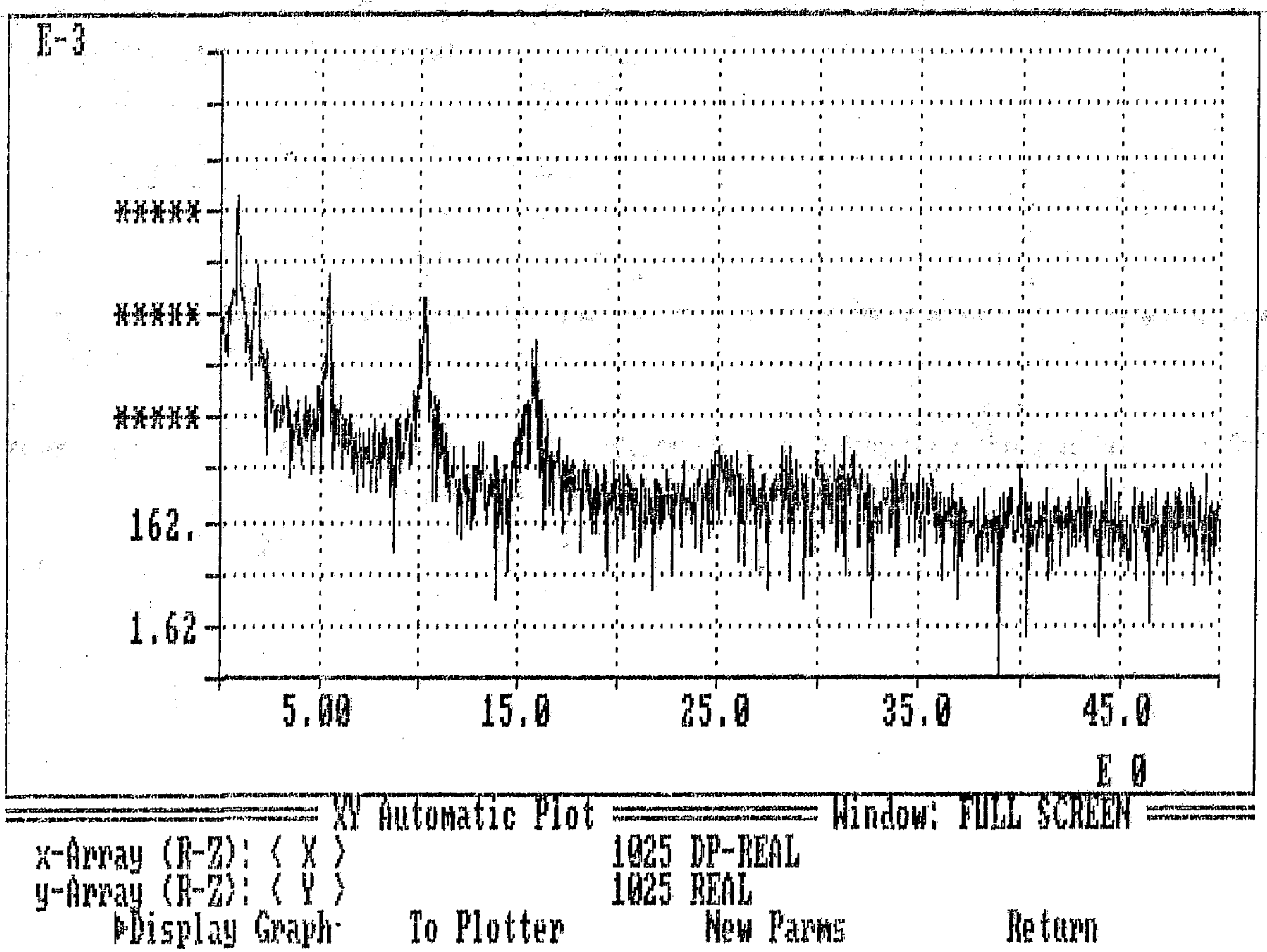


Figure 36. TYPE 31/30 - S1 FFT POWER CURVE

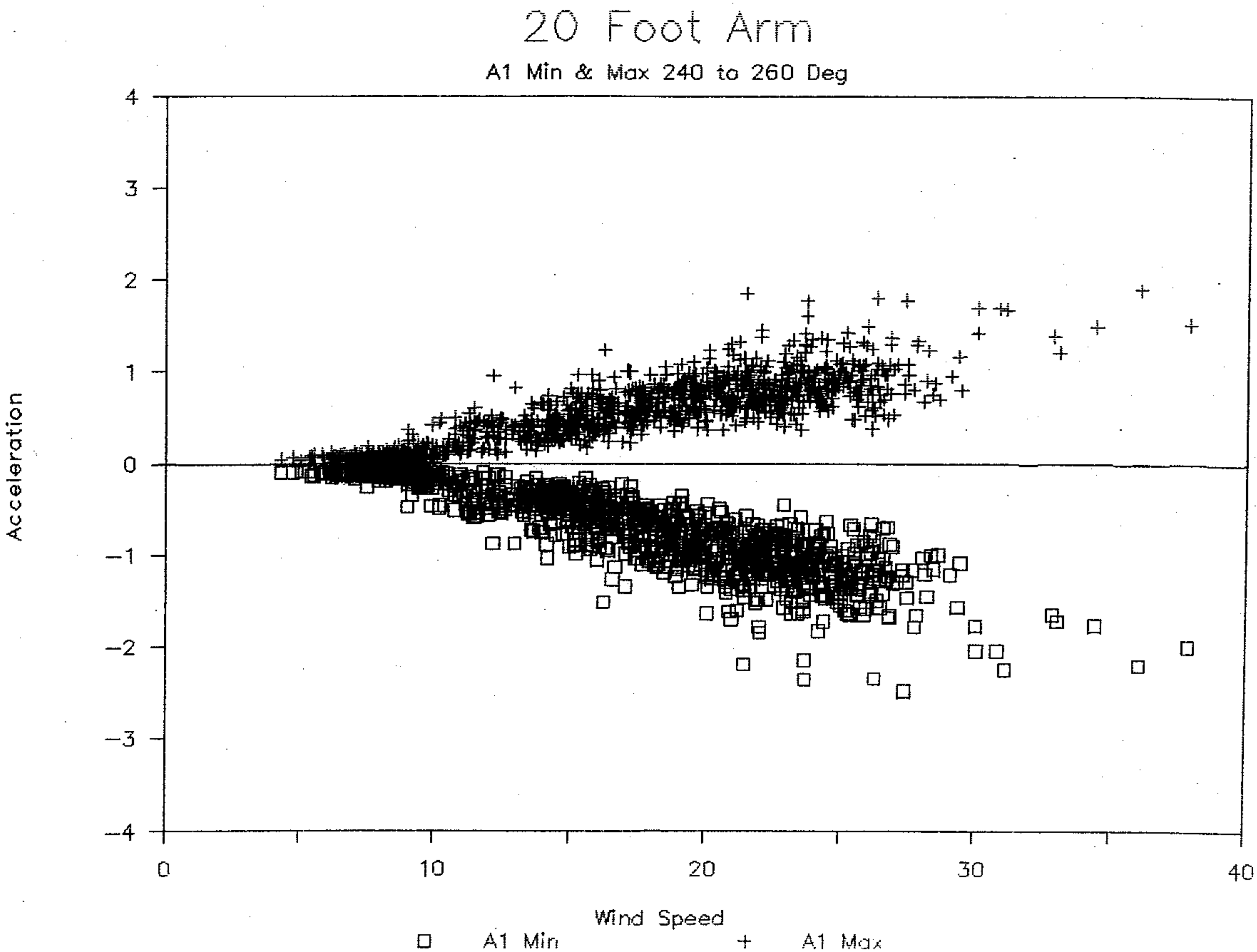


Figure 37. TYPE 31/20 - LUMINAIRE ACCELERATION (A1)

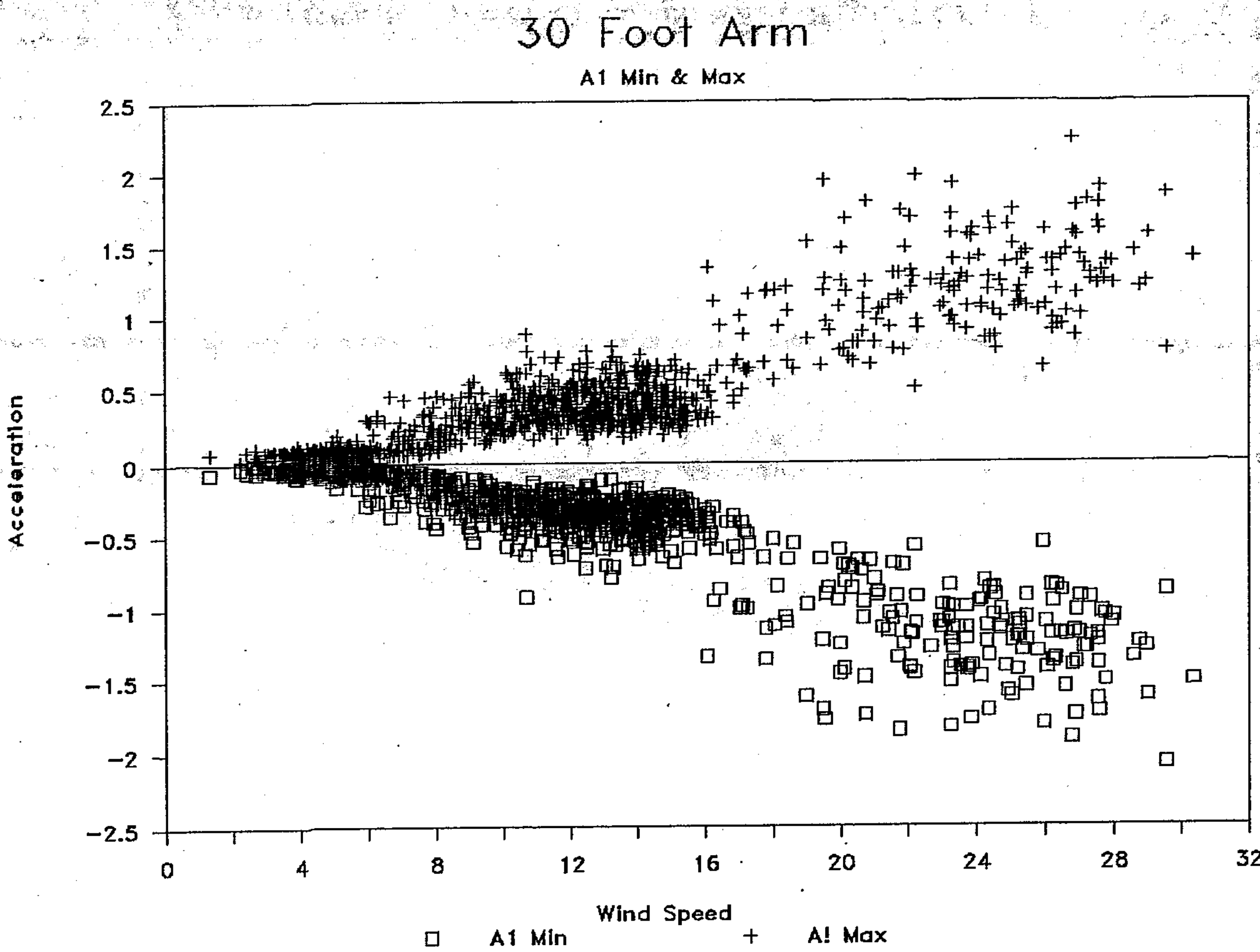


Figure 38. TYPE 31/30 - LUMINAIRE ACCELERATION (A1)

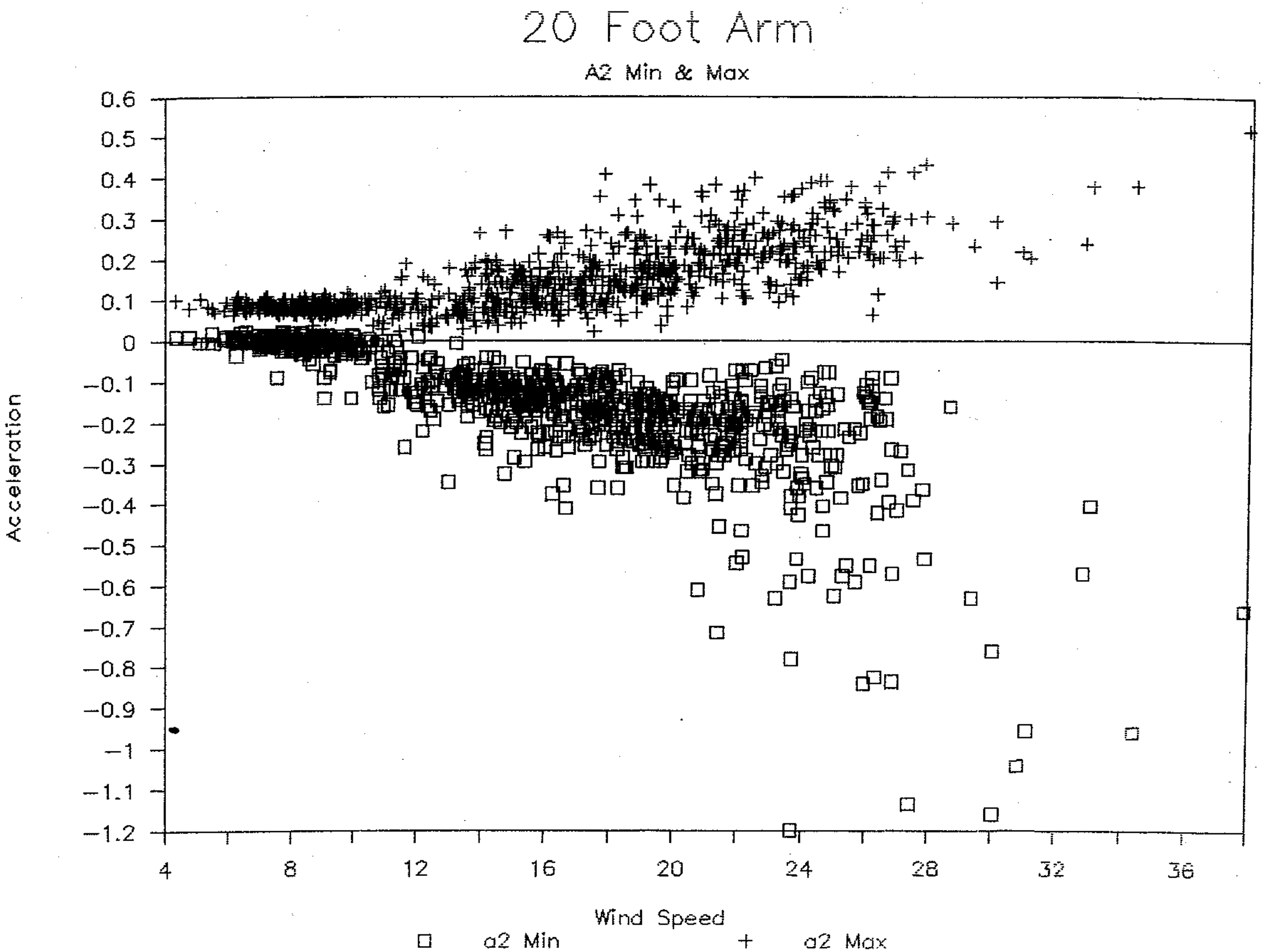


Figure 39. TYPE 31/20 - LUMINAIRE ACCELERATION (A2)

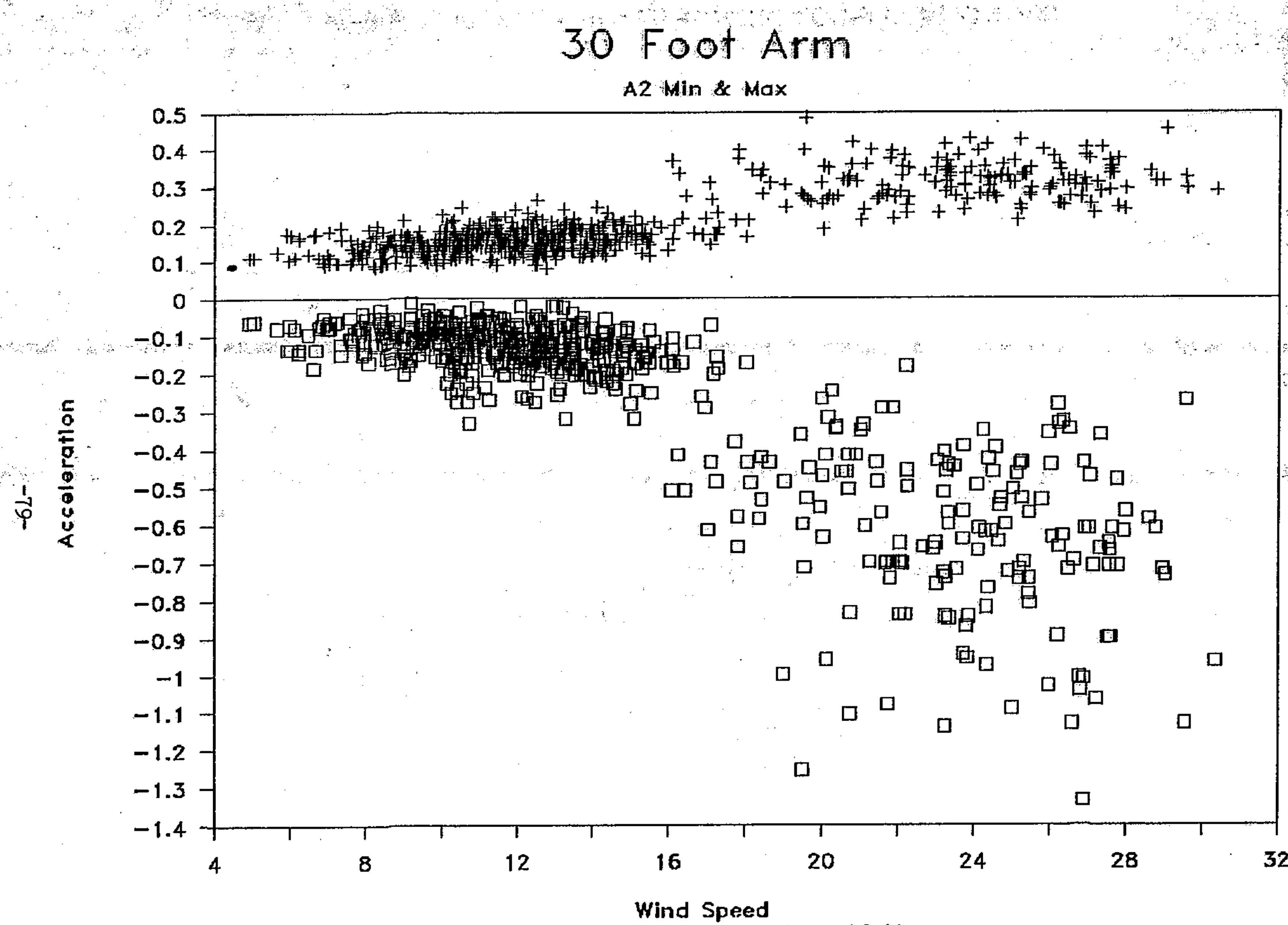


Figure 40. TYPE 31/30 - LUMINAIRE ACCELERATION (A2)

16. FIELD INSTALLATION PROBLEMS

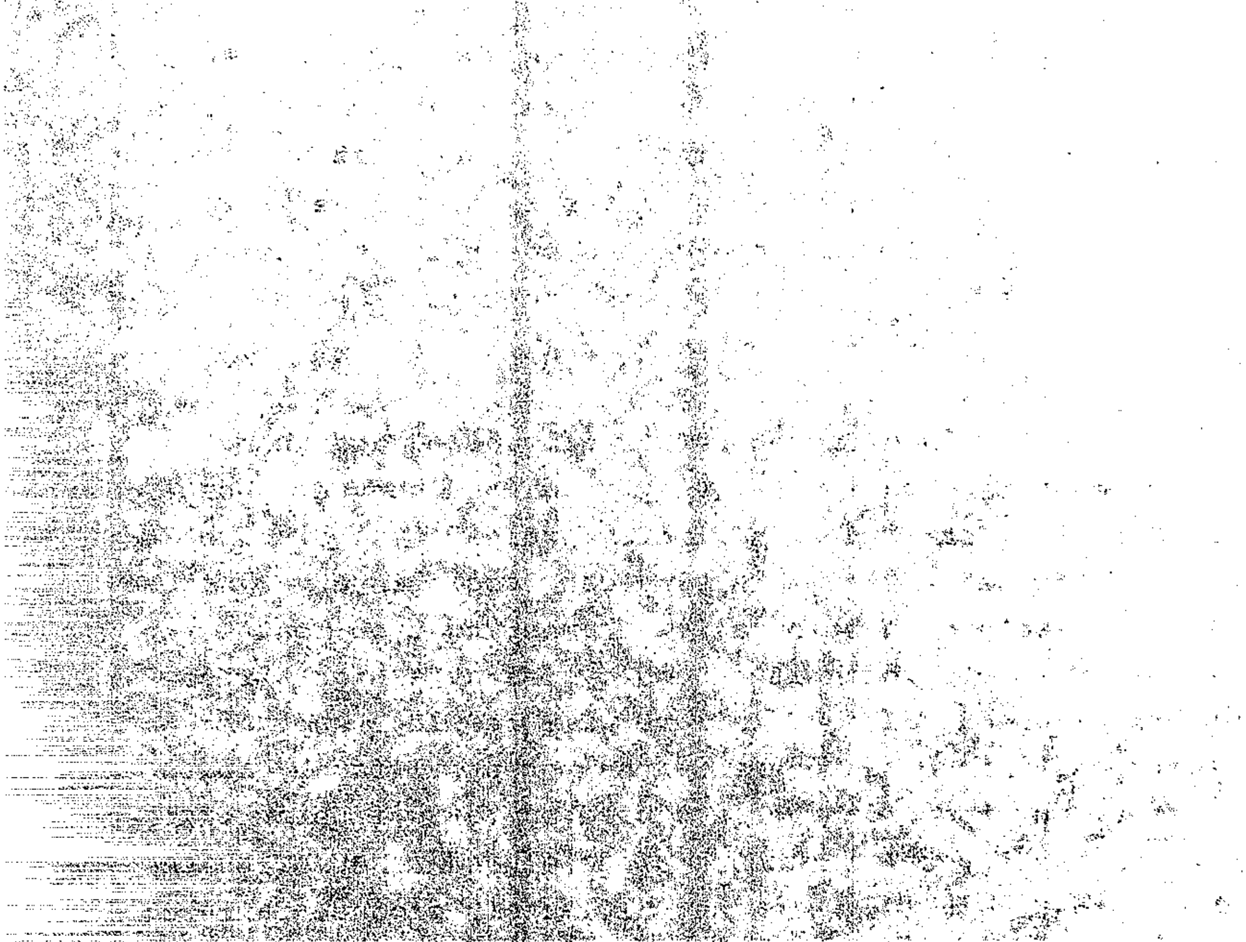
Some anchor bolt failures occurred after the diameter was increased from 7/8-inch to 1 inch. We now conclude, because of the load ranges measured, that these are probably related to construction personnel installation errors. Installation problems varied from trying to bend the high-strength anchor bolts after the concrete had cured, to over or under tightening the fasteners.

The potential for damage to high-strength anchor bolts when bent cold, is due probably to crack initiation at thread roots, i.e., a stress riser point. After this initial loading past the stress fatigue limit the crack growth accumulates as much lower stress cycles occur (18). When the cross section carrying the pole load is reduced such that the ultimate stress limit is exceeded, the bolt fails.

The pole base, bolts, and fasteners are galvanized and this surface treatment is occasionally very rough and uneven. When the fasteners are installed with minimum preload, the crush of these many galvanized surfaces in time can result in a very loose connection. A loose connection allows hammering-type load reversals on the bolt, which if enough cycles at a high-stress range are experienced, fatigue failure will result. Another problem with galvanized fasteners is the potential for hydrogen embrittlement. Hydrogen damage is caused by the diffusion of hydrogen into the crystal structure of steel and reacts with the carbon thus creating voids which may ultimately produce failure (19). A baking treatment after pickling but before galvanizing will drive off the hydrogen and help prevent this condition.

An additional type of failure can be produced by stress corrosion. This is caused by alternating stresses set up by vibration, or other periodic mechanical or thermal changes (19).

The failure mode develops along stress concentration points and tends to be transcrystalline. Where cracks develop, corrosion can penetrate into the metal and accent the problem.



17. ENVIRONMENTAL EFFECTS

Fatigue failure is greatly accelerated if an initial crack is present at a location of high stress. There are other factors which can cause the initiation of a crack, or change the rate of, fatigue failure. These can include humidity, salt-water, temperature, acidity, etc. In some cases, the installation situation may leave the anchor bolts exposed during the winter months to salt used on the roadway for snow removal. A saltwater environment will strongly influence the time to crack initiation and increase the growth rate for aluminum and steel components. The chloride in the salt can cause quick depletion of the protective zinc layer and lead to early pitting and rusting. The resulting corrosion pitting can initiate cracking and accelerate the reduction of the bolt cross section. The smaller cross sectional area will raise the stress level to a point where failure by fatigue will occur.

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APPENDIX A

Test Summary - 1" Diameter Anchor Bolt

To: Ken Pinkerman

April 8, 1987

Prepared by: Jeffrey M. Ziehm

TransLab - Structural Materials Branch

Test Summary for 1" Dia. A449 Anchor Bolts/A194 Nut Used in Type 31 Light Std. Wind/Stress Tests Type 31 Light Std. from Caltrans Std. Plan ES-6E

EA: 54-637330

Anchor Bolt is ASTM A449 - Type 1 Steel

Nuts are ASTM A194, grade 2H

<u>Tests Passed:</u>

Anchor Bolt ASTM A449 & F606

ASTM A449 & A751

ASTM A449, A153 & B695

Nuts - ASTM A563, A194 & A370 (Mechanical) Thread tolerances as per ASTM A563 and Caltrans Standard Specifications 86-2.03

<u>Test Failed:</u>

Anchor Bolt - ANSI b1.1 CLASS 2A (Thread Tolerance)

1" Dia. ASTM A449 Anchor Bolt

<u>Mechanical Tests</u> (ASTM A449 & F606) See Test Report #1.

Alternative Proof Load - Yield @ 0.2% offset.

The bolt was gradually loaded while the elongation in the bar was measured with a dial gage mounted between the grips in the testing machine. The resulting loads and deflections were recorded on the Stress/Strain Worksheet and used to produce a load/elongation curve. After plotting the points, several different slopes were used to fit a straight line to the points representing the elastic portion of the curve. Then a parallel line was drawn offset to the right of the 1st line by an amount equal to 0.2% of the length of the specimen measured between the machine grips. Since the length of the specimen being stretched was 6.25", the offset line was drawn (6.25)(.002) or 0.0125" to the right and the Yield Point is the load at the intersection of the two lines. This produced the graphs in Figures 1A through 1E. Figure 1A was chosen as most representative which resulted a Yield Point of 74,000 lbs.

Yield Point @ 0.2% offset = 74000 lbf. > min. 55,750 lbf. required. Therefore the test passes. Or load / stress area = 74000 lb./ 0.606 square inches = 122,112 psi. > min. 92,000 psi. required, therefore, test passes.

Ultimate Load (load at failure) was 83,650 lbf. > 72,700 lbf. therefore test passes. Or load/stress area = 83,650 lb. / 0.606 square inches = 138,036 psi. > 120,000 psi. required, therefore, test passes.

Hardness (Rockwell C Scale) See Test Report #2.

A transverse section of the bar was cut and the flat ends sanded smooth. A set of 4 readings were taken and averaged from each flat end of the transverse section. The readings were taken at midradius, 90 degrees to one another. A set of 5 readings was also averaged from the outer shaft of the bolt after the zinc was removed and the bolt sanded smooth. The hardness range required for 1" diameter A449 bolt for Rockwell C Scale = 25 min. to 34 max.

Test #1 Average = 25.05 > 25 and < 34 therefore the test passes.
Test #2 Average = 25.275 > 25 and < 34 therefore the test passes.
Test #3 Average = 27.34 f> 25 and < 34 therefore the test passes.

<u>Chemical Tests</u> (ASTM A449 & A751) See Test Report #3.

Chemial	% Required (Type 1)	Tested	Passed/Failed
Carbon	0.25 - .58	0.51	Passes
Manganese	0.56 (min.)	0.82	Passes
Phosphorus	0.048 (max.)	Non Detected	Passes
Sulfur	0.058 (max.)	0.04	Passes

<u>Zinc Galvanizing</u> (ASTM A449, A153 & B695) See Test Report #4.

Diameter of Bolt - With Galvanizing 0.921" Without Galvanizing 0.902" Actual thickness of Coating = 0.921-0.902/2(3x10E1/2) = 0.0055" 1 oz./sq. ft. = 0.0017 in. thickness.

Actual Wt. of Zinc Coating = 0.0095"/0.0017"(3x10E1/2) = 3.23 oz./sq. ft. Min. Wt. of Zinc Coating for Individual Specimen - Class C Material = 1.25 Fastener = 3.23 oz./sq. ft. > 1.25 oz./sq. ft., therefore, test passes.

<u>Thread Tolerances</u> (ANSI B1.1, for bolt & ASTM A563)
Anchor Bolt: 1-8 unc - Class 2A, before galvanizing.

Max. Pitch Dia. for Class 2A fit = 0.9168"
Min. Pitch Dia. for Class 2A fit = 0.9100"

Pitch Diameter after stripping zinc = 0.903" on one end of Bolt and 0.902" on the other end. Threads on both ends of Bolt < 0.9100", therefore, pitch diameter is too small for class 2A fit - Test Fails.

APPENDIX B

Test Summary - 1" Dia. ASTM A194 Grade 2H Galvanized Heavy Hex Nuts

Mechanical Tests (ASTM A563, A194 & A370) See Test Report #5. Hardness (Rockwell C Scale) - The bearing face of the nut was sanded smooth and free of zinc. A set of 5 readings were then taken on the bearing face and averaged, giving an average hardness of 25.88. The hardness range for a 1" diameter A194 Grade 2H Nut on the Rockwell C Scale = 24 to 38.

24 < 25.88 < 38 therefore test passes.

Proof load - Nut was tested on a threaded mandrel made of S-7 steel with Class 3A thread tolerances.

1" Nominal Size Nut - Grade 2H Heavy Hex - was proof loaded to 106,000 lbf. based on a proof stress of 175,000 psi.

After the load was removed the threads were inspected and it was found that no stripping, rupture or any detectable damage to the threads had resulted. Therefore, the nut passes the proof loading test.

Thread Tolerances ANSI B1.1, Class 2B as per Caltrans Standard Specifications Section 86-2.03.

The nuts were checked with a thread gage for galvanized products and it was found that nut overtapping conformed to Caltrans Standard Spec. 86-2.03 and was not excessive. Therefore, the nut passes test.

The data and test reports are on file at TransLab.

APPENDIX C
StrainSert Calibration Data

STRAINSERT CALIBRATION DATA

Department of Transportation Sacramento, CA Customer P.O. No. 54F224	Q-8641 Strainsert Job No. Date: 11-3-86 Sign: Jm

Transducer: Threaded Stud, as supplied by customer
(SS-FB) 1-8NC x 24-lg.
(350Ω/150°F) H T1 K S

Gages: EA-06-100ZF-350 Type: H
Service Temp.: 150°F Max. Ins. Res.: Over 10,000 megohms

CAL TEMP 68°F S/N Q8641-2

LOAD POUNDS	STRAIGHT LINE SIGNAL mv/V	DEVIATIONS-μv/V RUN-1	RUN-2	RUN-3	REP μv/V
0	0	0	0	0	0
5,000	0.300	1	1	1	0
10,000	0.600	0	0	0	0
15,000	0.900	-1	-1	-1	0
20,000	1.200	-1	-1	-1	0
25,000	1.500	0	-1	0	1
20,000	1.200	0	0	1	1
15,000	0.900	0	0	-1	1
10,000	0.600	0	0	0	0
5,000	0.300	1	0	0	1
0	0	0	0	0	0
	HYSTERESIS	1	1	2	

CALIBRATION ANALYSIS:

NON-LINEARITY: 1 PARTS IN 1,500 = 0.07%

REPETITION
LOADING : 1 PARTS IN 1,500 = 0.07%
UNLOADING: 1 PARTS IN 1,500 = 0.07%
ZERO LOAD: 0 PARTS IN 1,500 = 0.00%
MAX. LOAD: 1 PARTS IN 1,500 = 0.07%

END POINT : 1 PARTS IN 1,500 = 0.07%

HYSTERESIS : 2 PARTS IN 1,500 = 0.13%

CALIBRATION RESULTS ARE TRACEABLE TO N. B. S.

SHUNT CAL: 73,000 OHMS CONNECTED E+ TO S+ = + 20,216 POUNDS.

STRAINSERT CALIBRATION DATA

Department of Transportation Sacramento, CA	Q-8641 Strainsert Job No.
	Date: 11-4-86
Customer P.O. No. 54F224	Sign: Jm

Transducer: Threaded Stud, as supplied by customer
(SS-FB) 1-8NC x 24-lg.
(350Ω/150^{0}F) H T1 K S

Gages: EA-06-100ZF-350 Type: H
Service Temp.: 150^{0}F Max. Ins. Res.: Over 10,000 megohms

CAL TEMP 68°F S/N Q8641-3

LOAD POUNDS	STRAIGHT LINE SIGNAL mV/V	DEVIATIONS-μV/V RUN-1	RUN-2	RUN-3	REP μV/V
0	0	0	0	0	0
5,000	0.300	3	2	2	1
10,000	0.600	3	2	2	1
15,000	0.900	2	1	1	1
20,000	1.200	1	0	0	1
25,000	1.500	-5	-6	-6	1
20,000	1.200	-3	-4.5	-4	1.5
15,000	0.900	-5	-6	-6	1
10,000	0.600	-10	-10	-10	0
5,000	0.300	-8	-9	-9	1
0	0	0	0	0	0
	HYSTERESIS	13	12	12	

CALIBRATION ANALYSIS:

NON-LINEARITY: 6 PARTS IN 1,500 = 0.40%

REPETITION
LOADING : 1 PARTS IN 1,500 = 0.07%
UNLOADING: 1.5 PARTS IN 1,500 = 0.10%
ZERO LOAD: 0 PARTS IN 1,500 = 0.00%
MAX. LOAD: 1 PARTS IN 1,500 = 0.07%

END POINT : 6 PARTS IN 1,500 = 0.40%

HYSTERESIS : 13 PARTS IN 1,500 = 0.87%

CALIBRATION RESULTS ARE TRACEABLE TO N. B. S.

SHUNT CAL: 73,000 OHMS CONNECTED E+ TO S+ = + 20,200 POUNDS.

APPENDIX D
Accelerometer Data Sheets

$245.00

171

11-14-61

Statham INSTRUMENTS, INC.
12401 WEST OLYMPIC BLVD., LOS ANGELES 64, CALIFORNIA

ACCELEROMETER DATA SHEET

DATE: 11-6-61
CUSTOMER: STATE OF CALIFORNIA
CUSTOMER'S ORDER NO. 13413 Est. No. 131465
OUR PRODUCTION NO. 1211-1-1F
OUR SPECIFICATION NO. 12417-5

This report has been prepared by our Standards Laboratory. The following data are important to the operation of the accelerometer:

ACCELEROMETER MODEL NO. A301-5-350
SERIAL NO. 171
ACCELERATION RANGE: ± 5 G
INPUT TERMINALS: 1 and 4 (Green and Red)
OUTPUT TERMINALS: 2 and 3 (Black and White)
EXCITATION — E: 9 volts
INPUT RESISTANCE — R_{in}: 343.2 ohms
OUTPUT RESISTANCE — R: 343.2 ohms
CALIBRATION FACTOR — F: 548.8 microvolts (open circuit) per volt per g

The strain sensitive resistance wire elements of the transducer are arranged in the form of a Wheatstone bridge. Either *ALTERNATING* or *DIRECT* current may be used to excite the accelerometer, depending upon the requirements of the indicating or recording instrument.

5cps = natural frequency

bc

Form #1 Statham Instruments, Inc., 12401 W. Olympic Blvd., Los Angeles 64

Form No. 206 RP

Form #B1

FORM #104A

1-3-4 245/100

172 172

Statham INSTRUMENTS, INC.
12401 WEST OLYMPIC BLVD., LOS ANGELES 64, CALIFORNIA

11-14-61

ACCELEROMETER DATA SHEET

DATE: 11-6-61
CUSTOMER: STATE OF CALIF.
CUSTOMER'S ORDER NO. 13413, Est. No. 131465
OUR PRODUCTION NO. 1211-1-1F
OUR SPECIFICATION NO. 12417-5

This report has been prepared by our Standards Laboratory. The following data are important to the operation of the accelerometer:

ACCELEROMETER MODEL NO. A301-5-350
SERIAL NO. 172
ACCELERATION RANGE: ± 5 G
INPUT TERMINALS: 1 and 4 (Green and Red)
OUTPUT TERMINALS: 2 and 3 (Black and White)
EXCITATION — E: 9 volts
INPUT RESISTANCE — R_{in}: 344.8 ohms
OUTPUT RESISTANCE — R: 344.7 ohms
CALIBRATION FACTOR — F: 545.3 microvolts (open circuit) per volt per G

The strain sensitive resistance wire elements of the transducer are arranged in the form of a Wheatstone bridge. Either *ALTERNATING* or *DIRECT* current may be used to excite the accelerometer, depending upon the requirements of the indicating or recording instrument.

5 cps = natural frequency

1.58 meg = .1g

bc

Form #1 Statham Instruments, Inc., 12401 W. Olympic Blvd., Los Angeles 64

Form No. 206 KP

Form #B1

FORM #104A

I 5 G

173

Statham INSTRUMENTS, INC.

12401 WEST OLYMPIC BLVD., LOS ANGELES 64, CALIFORNIA

ACCELEROMETER DATA SHEET

DATE: 11-30-61
CUSTOMER: STATE OF CALIF.
CUSTOMER'S ORDER NO. 13413, Est. No. 131465
OUR PRODUCTION NO. 1211-1-1F
OUR SPECIFICATION NO. 12417-5

This report has been prepared by our Standards Laboratory. The following data are important to the operation of the accelerometer:

ACCELEROMETER MODEL NO. A301-5-350
SERIAL NO. 173
ACCELERATION RANGE: ± 5 G
INPUT TERMINALS: 1 and 4 *(Green and Red)*
OUTPUT TERMINALS: 2 and 3 *(Black and White)*
EXCITATION — E: 9 volts
INPUT RESISTANCE — R_{in}: 343.6 ohms
OUTPUT RESISTANCE — R: 343.5 ohms
CALIBRATION FACTOR — F: 579.0 microvolts (open circuit) per volt per G

The strain sensitive resistance wire elements of the transducer are arranged in the form of a Wheatstone bridge. Either *ALTERNATING* or *DIRECT* current may be used to excite the accelerometer, depending upon the requirements of the indicating or recording instrument.

1.48 meg = .1g

RS Service Manual

bc

Form #1 Statham Instruments, Inc., 12401 W. Olympic Blvd., Los Angeles 64

Form No. 206 HP

10-59 10M 3-5218 HP

APPENDIX E
Signal Conditioning Specifications

1.0 DESCRIPTION

1.1 GENERAL

The 2300 Series instruments comprise a versatile multi-channel system for conditioning and amplifying low-level signals from strain gages (or strain-gage transducers) for display or recording on external equipment. Each 2310 Signal Conditioning Amplifier is separately powered and electrically isolated from all others (and can be powered with separate line cords), although normally groups of amplifiers are inserted into a multi-channel rack adapter or portable enclosure.

The Model 2350 Rack Adapter accepts up to ten 2310 Amplifiers for mounting in a standard 19-in *(483-mm)* rack; the Model 2360 Portable Enclosure accepts up to four 2310 Amplifiers for more portable use.

Each Model 2310 Amplifier incorporates precision high stability bridge completion resistors and dummy gages, and four shunt-calibration resistors, and is complete and ready for use as delivered – only ac power is required via the Portable Enclosure, Rack Adapter or separate ac line cord. Input and output connectors are supplied with each amplifier.

1.2 SIGNIFICANT FEATURES

The 2300 Series is designed to provide features essential for accurate stress analysis data in a broad range of measurement applications. Principal features include:

- Fully adjustable calibrated gain from 1 to 11 000.
- Accepts all strain gage inputs (foil or piezoresistive), potentiometers, DCDT's, etc.
- Bridge excitation from 0.5 to 15 Vdc (12 steps).
- Input impedance above 100 megohms.
- Three simultaneous buffered outputs: ±10V, ±1.4V (for tape recorders), and a 75-mA galvanometer output.
- Wide-band operation exceeding 25 kHz, −0.5 dB at all gains and output levels.
- Four-frequency active filter (10 to 10 000 Hz).
- Dual-range (±5000 and ±25 000$\mu\epsilon$) automatic bridge balance, with keep-alive power to preserve balance for months without external power.
- Dual-polarity 2-step double-shunt calibration.
- Optional remote calibration and auto balance reset.
- Playback mode to filter and observe or re-record previously recorded magnetic tape data.
- and many other convenience features.

2.0 SPECIFICATIONS

All specifications are nominal or typical at +23°C unless noted.

2.1 2310 SIGNAL CONDITIONING AMPLIFIER

INPUT

Strain gages: quarter, half, or full bridge (50 to 1000Ω). Built-in 120Ω and 350Ω dummy gages.

Transducers: foil or piezoresistive strain gage types.

Potentiometers.

DCDT inductive transducers.

EXCITATION

Twelve settings: 0.5, 0.7, 1, 1.4, 2, 2.7, 3.5, 5, 7, 10, 12 and 15 Vdc ±1% max.

Current: 0-100 mA, min, limited at 175 mA, max.

Regulation (0-100 mA, ±10% line change): ±0.5 mV ±0.04%, max measured at remote sense point. (Local sense: −5 mV, typical, @ 100 mA, measured at plug.)

Remote sense error: 0.0005% per ohm of lead resistance (350Ω load).

Noise and ripple: 0.05% p-p, max (dc to 10 kHz).

Stability: ±0.02%/°C.

Level: normally symmetrical about ground; either side may be grounded with no effect on performance.

BRIDGE BALANCE

Method: counter-emf injection at pre-amp; automatic electronic; dual range; can be disabled on front panel.

Ranges (auto ranging):

±5000$\mu\epsilon$ (1% bridge unbalance or 2.5 mV/V), resolution 2.5$\mu\epsilon$ (0.0012 mV/V).

±25 000$\mu\epsilon$ (5% bridge unbalance or 12.5 mV/V), resolution 12.5$\mu\epsilon$ (0.006 mV/V).

Balance time: 2 seconds, typical.

Manual vernier balance range: 100$\mu\epsilon$ (0.050 mV/V).

Interaction: essentially independent of excitation and amplifier gain.

Storage: non-volatile digital storage without line power for up to 2 years.

SHUNT CALIBRATION

Circuit (two-level, dual polarity): Single-shunt (for stress analysis) across any bridge arm, including dummy gage.

Double-shunt (for transducers) across opposite bridge arms.

Provision for four dedicated leads to shunt external arms.

CAL circuit selected by switches on p.c. board.

Standard factory-installed resistors (±0.1%) simulate:

±200 and ±1000$\mu\epsilon$ @ GF=2 across dummy half bridge;

±1000$\mu\epsilon$ @ GF=2 across dummy gage (120Ω and 350Ω).

±1 mV/V (double-shunt) for 350Ω transducer.

Remote-operation relays (Option Y): four relays (plus remote-reset relay for bridge balance and relay for excitation on/off). Each relay requires 10 mA @ 5 Vdc, except excitation on/off 25 mA.

AMPLIFIER

Gain: 1 to 11 000 continuously variable. Direct-reading ±1%, max.

10-turn counting knob (X1 to X11) plus decade multiplier (X1 to X1000).

Frequency response (all gains >5, full output):

dc coupled: dc to 25 kHz, −0.5 dB max.
dc to 65 kHz, −3 dB typical at 40% output;
ac coupled: 5 Hz to 25 kHz, −0.5 dB

Input impedance: 100 mΩ, min, differential or common-mode, including bridge balance circuit.

Bias current: ±0.01 μA, typical, each input.

Source impedance: 0 to 1000Ω each input.

Common-mode voltage: ±10V.

Common-mode rejection (gain over X100):

Shorted input: 100 dB, min, at dc; 90 dB, min, dc to 1 kHz;

350Ω balanced input: 90 dB, typical, dc to 1 kHz.

Stability (gain over X100): ±2 μV/°C, max, RTI (referred to input).

Noise (gain over X100, all outputs):

0.01 to 10 Hz: 1μV p-p RTI.

0.5 to 50 kHz: 5 μVrms, max, RTI

FILTER

Characteristic: low-pass active 2-pole Butterworth standard.

Frequencies (−3 ±1 dB): 10, 100, 1000 and 10 000 Hz and wide-band.

Outputs filtered: any 1 or 2 or all (switch-selected on p.c. board).

AMPLIFIER OUTPUTS

Standard output: ±10V @ 5 mA, min.

Tape output: ±1.414V (1 Vrms) @ 5 mA, min.

Galvanometer output: ±10V @ 75 mA, min, current-limited at 100 mA, max (minimum load resistance for 0.05% linearity: 50Ω).

Galvanometer attenuator (0-100%) and zero adjust (±1V) on front panel.

Linearity @ dc: 0.02%.

Any output can be short-circuited with no effect on others.

PLAYBACK

Input: ±1.414V full scale; input impedance 20 kΩ.

Gain: X1 to tape output; X7.07 to standard output.

Filter selection: as specifed above.

Outputs: All three, as specified above.

POWER

105 to 125V or 210 to 250V (switch-selected), 50/60 Hz, 10 watts, max.

Keep-alive supply (for bridge balance): 2 Eveready S76E or equal. Shelf-life (approximately 2 years).

SIZE & WEIGHT

Panel: 8.75 H x 1.706 W in *(222.2 x 43.3 mm).*

Case depth behind panel: 15.9 in *(404 mm).*

Weight: 6 lb *(2.7 kg).*

2.2 2350 RACK ADAPTER

APPLICATION

Fits standard 19-in *(483-mm)* electronic equipment rack.

Accepts up to ten 2310 Amplifiers. AC line completely wired.

Wiring for remote calibration with Option Y.

POWER

2-ft *(0.6-m)* 3-wire line cord; 10-ft *(3-m)* extension cord supplied.

Fuse: 1 A size 3 AG *(32 x 6.4 mm dia.).*

Receptacle to accept line cord from adjacent 2350 Rack Adapter.

SIZE & WEIGHT

8.75 H x 19 W x 17.87 D in overall *(222 x 483 x 454 mm).*

13.5 lb *(6.1 kg)*

2.3 2360 PORTABLE ENCLOSURE

DESCRIPTION

Convenience enclosure to accept up to four 2310 Amplifiers.

AC wiring complete.

Wiring for remote calibration with Option Y.

POWER

8-ft *(2.4-m)* detachable 3-wire cord.

Fuse: 1/2 A size 3 AG *(32 x 6.4 mm dia.).*

APPENDIX F
Wind Sensor Calibration

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
OFFICE OF TRANSPORTATION LABORATORY

ANEMOMETER
CALIBRATION REPORT

FOR DISTRICT : 19
LOCATION : Transportation Laboratory *DATE* : 8/ 2/89
INSTRUMENT MAKE AND MODEL : Climet 011-1
SERIAL AND/OR CHC NO. : No I. D.

WIND TUNNEL CHC NO. : 12186
MANOMETER : Dwyer Model 8774 - 0 to 1.0 inches of water.
PITOT TUBE : United Sensor and Controls - PAC-8-KL

CALIBRATION DATA

TEMPERATURE WET BULB	DRY BULB	IND.	MAND.	BAROMETRIC PRESS.	WIND SPEED ACTUAL	INDICATED
67.5	94	-	0.727	29.90	39.75	40.4
67.5	93.5	-	0.403	29.90	29.59	30.0
67.5	93.5	-	0.187	29.90	20.16	20.2
67.5	91.5	-	0.046	29.90	9.88	10.0
67	89	-	0.011	29.90	4.87	4.8
67	89	-	0.000	29.90	0.00	0.4

LEAST SQUARES REGRESSION -
Slope = 1.0108
Intercept = 0.0702
Correlation coefficient = 0.99990

COMMENTS :

COPIES : File

CALIBRATION BY : R.L. Cramer

Signed: R L Cramer

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
OFFICE OF TRANSPORTATION LABORATORY

WIND DIRECTION VANE
CALIBRATION REPORT

DATE : 8/ 2/89

FOR DISTRICT : 19
LOCATION : Transportation Laboratory
INSTRUMENT MAKE AND MODEL : Climet 012-10
SERIAL NO. : 549
TRANSLATOR MAKE AND MODEL : Climet 060-10
CHC NO. : 11793

CALIBRATION DATA

Degree Wheel Setting	Indicated Direction
0°	4°
90°	92°
180°	179°
270°	269°
360°	357°
450°	447°
540°	178°
450°	447°
360°	357°
270°	269°
180°	175°
90°	92°
0°	4°

LEAST SQUARES REGRESSION - (data logger printout)
Slope = 0.9881
Intercept = 2.64
Correlation coefficient = 0.99998

COMMENTS :

COPIES : File

CALIBRATION BY : R.L. Cramer

Signed: RL Cramer

APPENDIX G
Wind Loading Data Reduction

WIND LOADING DATA REDUCTION

The raw data was moved from the mag tapes to the PC and placed in data files with following format:

The data is divided into blocks of 32k bytes each. The blocks are numbered sequentially and given matching file names (B0001, B0002, B0003 etc.). The files are stored on 10 meg data cartridges, 300 blocks to a cartridge (300 files times 32k each = 9,830,400 bytes). Each of the mag tapes produces 2 data cartridges.

The blocks or files are binary data which are 2000 'records', each composed of 8-2 byte integers. Each 'record' is one of four possible data types and the type of data contained in each 'record' is determined by examining the left most 3 bits of the first byte:

```
 byte 1     byte 2     byte 3
00000000   00000000   00000000   etc.
---
```

	First 3 bits	Data Type
1.	000	Header record
2.	001	Clock and Wind data
3.	011	Accelerometer data
4.	100	Accelerometer & Strain data

Within each 'record' the data contained in the 8-2 byte fields is as follows:

---

1. HEADER RECORD
(header records are normally only written once per tape)

1st 2 byte integer	Julian date (after stripping out the record type from the 1st 3 bits)
2nd 2 byte integer	Not Used
3rd 2 byte integer	Not Used
4th 2 byte integer	Location Code
5th 2 byte integer	Tape Number
6th 2 byte integer	Wind Speed On
7th 2 byte integer	Not Used
8th 2 byte integer	Not Used

---

2. CLOCK & WIND DATA
   (normally written every tenth of a second)

1st 2 byte integer	Not Used
2nd 2 byte integer	Minutes since midnight
3rd 2 byte integer	Tenths of a second into minute (divide by 10 to convert to seconds)
4th 2 byte integer	Wind Speed (multiply by 0.08 to convert to mph)
5th 2 byte integer	Wind Direction (multiply by 0.54 to convert to degrees)
6th 2 byte integer	Not Used
7th 2 byte integer	Not Used
8th 2 byte integer	Not Used

---

3. ACCELERATION DATA
   (written every 0.002 seconds or 0.0033 seconds)

1st 2 byte integer	Acceleration 1(1) (after stripping out the record type from the 1st 3 bits)
2nd 2 byte integer	Acceleration 2(1)
3rd 2 byte integer	Acceleration 3(1)
4th 2 byte integer	Not Used
5th 2 byte integer	Not Used
6th 2 byte integer	Not Used
7th 2 byte integer	Not Used
8th 2 byte integer	Not Used

---

4. ACCELERATION & STRAIN DATA
   (normally written every 0.01 seconds)

1st 2 byte integer	Acceleration 1(1) (strip out the record type from the 1st 3 bits)
2nd 2 byte integer	Acceleration 2(1)
3rd 2 byte integer	Acceleration 3(1)
4th 2 byte integer	Strain 1(2)
5th 2 byte integer	Strain 2(2)
6th 2 byte integer	Strain 3(2)
7th 2 byte integer	Strain 4(2)
8th 2 byte integer	Not Used

(1) For all Accelerometer data multiply by 5 and divide by 1000 to convert to g's)
(2) For all strain data divide by 120 to convert to micro inches)

It was decided to summarize the data for 12 second intervals so that each interval would provide enough data for the Fourier analysis and since the data collection was in 1 minute increments and 60 seconds is evenly dividable by 12. The raw data was processed with the WLSUM computer program (compiled Quick Basic). WLSUM provides summaries of each 12 seconds of data and writes the summary to a file which can be read by Lotus 1-2-3. Each 12 second summary contains the following information:

Tape ID	Tape Identification Number
Start Blk	Beginning block for the 12 sec summary
" Rec	Beginning record within the block for the summary.
" Min	Beginning minute in minutes past midnight for the summary.
" Sec	Beginning seconds of the beginning minute.
Total Sec	Total number of seconds of data that are included in the summary. Since data collection was set to terminate at 60 sec intervals the vast majority of the data summaries are for the full 12 sec. (except in cases of manual or abnormal data collection termination).
Wind Speed Avg	Average wind speed.
" " sd	Standard deviation of the wind speed. A indicator of gustiness.
" " min	Lowest wind speed during the 12 seconds.
" " max	Highest wind speed during the 12 seconds.
Wind Dir. Avg	Average wind direction (in degrees).
" " sd	Standard deviation of the wind direction.
" " min	Smallest or left most wind direction.
" " max	Highest or right most wind direction.
A1, A2 & A3 min	Lowest acceleration rate for each accelerometer during the 12 sec.
A1, A2 & A3 max	Highest acceleration rate during the 12 sec.
S1, S2, S3 & S4 min	Lowest strain reading for each strain gage during the 12 sec.
S1, S2, S3 & S4 max	Highest strain reading for each strain gage during the 12 sec.

The resulting Lotus 1-2-3 WK1 file, while quite large, (1,370,404 bytes for the 30 ft mast arm WK1 file) provided an easy method of analyzing the data. The data could then be sorted, selected and graphed on any of the various parameters to examine the effects of wind speed, direction, gustiness etc.

The power spectrum analysis was done using ASYSTANT, a numerical and statistical software package. ASYSTANT has the capability of doing a fast Fourier transformation (fft) on up to 4096 data points and the ability to graph the results. The program WL2ASYST.BAS (a modification of the WLSUM program) was used to extract the desired data from the blocks of raw data and write it in a form that could be imported into ASYSTANT.

```
'***************** Summarize wind data & write lotus file ***************
'*  WLSUM.BAS                                                            *
'*      Dick Wood                                                        *
'*           The 1-2-3 routines are adapted from programs published      *
'*           by PC Magazine in Dec. 88.                                  *
'*                                                                       *
'*           Some of the wind load data routines are adapted from        *
'*           earlier work by Charlie Fraizer                             *
'*************************************************************************
OPTION BASE 1
DECLARE SUB WriteNumber (Row%, Column%, ColWidth%, Fmt$, Number#)
DECLARE SUB WriteInteger (Row%, Column%, ColWidth%, Integ%)
DECLARE SUB WriteLabel (Row%, Column%, ColWidth%, Msg$)
DIM SHARED FileNum, Temp AS INTEGER
DIM ready AS INTEGER
DIM SHARED Rec%, NUM%(8), L$(8), H$(8)
DIM CN%(28)    ' Column widths
DIM A%(3), MaxA%(3), MinA%(3)
DIM S(4)
DIM MaxS(4), MinS(4)

'LOTUS Column Width Data
CN%(1) = 5: CN%(11) = 6: CN%(21) = 7
CN%(2) = 6: CN%(12) = 6: CN%(22) = 7
CN%(3) = 5: CN%(13) = 6: CN%(23) = 7
CN%(4) = 5: CN%(14) = 6: CN%(24) = 7
CN%(5) = 6: CN%(15) = 6: CN%(25) = 7
CN%(6) = 5: CN%(16) = 6: CN%(26) = 7
CN%(7) = 6: CN%(17) = 6: CN%(27) = 7
CN%(8) = 6: CN%(18) = 6: CN%(28) = 7
CN%(9) = 6: CN%(19) = 6
CN%(10) = 6: CN%(20) = 6

'TapeID$              '"F1", AvgWD#         '"F3", MinS(1)
'StartBLK$            '"F1", SigmaWD#       '"F3", MaxS(1)
'StartRecord%         '"F1", MinWD          '"F3", MinS(2)
'StartMM%             '"F1", MaxWD          '"F3", MaxS(2)
'"F1", StartSEC#      'MinA%(1)             '"F3", MinS(3)
'"F1", NumSec#        'MaxA%(1)             '"F3", MaxS(3)
'"F2", AvgWS#         'MinA%(2)             '"F3", MinS(4)
'"F2", SigmaWS#       'MaxA%(2)             '"F3", MaxS(4)
'"F2", MinWS          'MinA%(3)
'"F2", MaxWS          'MaxA%(3)

   Row% = 3               ' Lotus starts at 0,0   3 leaves 3 blank rows at top
  H2000 = 8192
  H1FFF = H2000 - 1
  H1000 = H2000 / 2
  H07FF = 2047
   zero = 0
  athou = 1000
 mnines = -9999
 pnines = 9999

FileNum = 2
CLS
LOCATE 10, 20
PRINT "enter Tape ID ";
INPUT TapeID$: TapeID$ = UCASE$(TapeID$)

'OPEN "A:" + TapeID$ + ".WKS" FOR BINARY AS #FileNum
OPEN "B:" + TapeID$ + ".WKS" FOR BINARY AS #FileNum

CLS
LOCATE 6, 20
PRINT "Writing Lotus summary file: A:"; TapeID$; ".WKS"
LOCATE 8, 20
PRINT "                     Start Time:"; TIME$
Temp = 0                ' 123 Opcode for start of file
PUT FileNum, , Temp
Temp = 2                ' data length=2 for following integer
PUT FileNum, , Temp
Temp = 1028             ' Lotus version number
```

```
PUT FileNum, , Temp      ' Ver 1 = 1028, Ver 2 = 1030

GOSUB WriteColWidth

'Init. vars
    ready = zero
    Jtime = zero
 LastTime = zero
     Rec% = zero
    NumR% = zero

     BLK% = 1
' ****************main program loop *************************
DO
'OpenInputFile:
   Bfile$ = LTRIM$(STR$(BLK%))
   WHILE LEN(Bfile$) < 4
      Bfile$ = "0" + Bfile$
   WEND
   Bfile$ = "b" + Bfile$
  IF BLK% < 300 THEN DIR$ = "D:" ELSE DIR$ = "E:"
             'DIR$ = "A:"
    ON ERROR GOTO AllDone
      OPEN "I", #1, DIR$ + Bfile$
      CLOSE #1
   LOCATE 10, 20
   PRINT DIR$ + Bfile$;
  OPEN "R", #1, DIR$ + Bfile$, 16
  FIELD #1, 1 AS L$(1), 1 AS H$(1), 1 AS L$(2), 1 AS H$(2), 1 AS L$(3), 1 AS H$(3), 1 AS L$(4), 1 AS H$(4), 1 AS L$(5), 1

  BLK% = BLK% + 1

 FOR Rec% = 1 TO 2000
   'Read 8 numbers from file
   GET #1, Rec%
   FOR I% = 1 TO 8
     NUM%(I%) = CVI(L$(I%) + H$(I%))
   NEXT I%

   Datatype% = INT(NUM%(1) / H2000) + 1
   IF Datatype% < 1 OR Datatype% > 4 THEN PRINT R%, ASC(H$), ASC(L$), Datatype%: STOP

    ON Datatype% GOSUB Header, Wind, Accel, AandS

 NEXT Rec%
 CLOSE #1
 LOOP
 GOTO AllDone
 ' **************** end main program loop ********************

Header:
  'PRINT R%, "Header"
RETURN

 ' **************** clock and wind data **********************
Wind:
   MM% = NUM%(2)
   SEC = NUM%(3) / 10
   WS = NUM%(4) * .08
   WD = NUM%(5) * .54
                        ' PRINT MM%, SEC, WS, WD
   Jtime = MM% + SEC / 60
   ElapsedTime = Jtime - LastTime
   IF ElapsedTime > .0025 THEN GOSUB writeit  ' the .0025 is min. which =.15 sec
   IF ready = zero THEN GOSUB ResetVars

   LastTime = Jtime

  SumWS = SumWS + WS
 SumWS2 = SumWS2 + WS ^ 2
  SumWD = SumWD + WD
 SumWD2 = SumWD2 + WD ^ 2
```

```
 IF WS > MaxWS THEN MaxWS = WS
 IF WS < MinWS THEN MinWS = WS
 IF WD > MaxWD THEN MaxWD = WD
 IF WD < MinWD THEN MinWD = WD

NumR% = NumR% + 1
IF NumR% >= 120 THEN GOSUB writeit

RETURN

' **************** accelerometer data **********************
Accel:
   IF ready = zero THEN RETURN
   NUM%(1) = NUM%(1) AND H1FFF
    IF NUM%(1) AND H1000 THEN
       NUM%(1) = -NUM%(1) AND H07FF
       NUM%(1) = -NUM%(1)
   END IF
   A%(1) = 5 * NUM%(1)
   A%(2) = 5 * NUM%(2)
   A%(3) = 5 * NUM%(3)
   FOR I% = 1 TO 3
      IF A%(I%) < MinA%(I%) THEN MinA%(I%) = A%(I%)
      IF A%(I%) > MaxA%(I%) THEN MaxA%(I%) = A%(I%)
       'PRINT A%(i%);
    NEXT I%
       'PRINT
   FOR I% = 1 TO 3
      A%(I%) = 5 * NUM%(3 + I%)
      IF A%(I%) < MinA%(I%) THEN MinA%(I%) = A%(I%)
      IF A%(I%) > MaxA%(I%) THEN MaxA%(I%) = A%(I%)
      'PRINT A%(i%);
    NEXT I%
     'PRINT
RETURN

' **************** accelerometer & strain data ***************
AandS:
   IF ready = zero THEN RETURN 'we're not ready till we find clock data
   NUM%(1) = NUM%(1) AND H1FFF
   IF NUM%(1) AND H1000 THEN
       NUM%(1) = -NUM%(1) AND H07FF
       NUM%(1) = -NUM%(1)
   END IF
   A%(1) = 5 * NUM%(1)
   A%(2) = 5 * NUM%(2)
   A%(3) = 5 * NUM%(3)
   FOR I% = 1 TO 3
      IF A%(I%) < MinA%(I%) THEN MinA%(I%) = A%(I%)
      IF A%(I%) > MaxA%(I%) THEN MaxA%(I%) = A%(I%)
      'PRINT A%(i%);
    NEXT I%
    FOR I% = 1 TO 4
      S(I%) = NUM%(3 + I%) / 120
      IF S(I%) < MinS(I%) THEN MinS(I%) = S(I%)
      IF S(I%) > MaxS(I%) THEN MaxS(I%) = S(I%)
      'PRINT S(i%);
    NEXT I%
     'PRINT
RETURN

' **************** write summary to 1-2-3 file ***************
writeit:
   IF NumR% < 3 THEN GOTO skiprite
   AvgWS# = SumWS / NumR%
   AvgWD# = SumWD / NumR%
   SigmaWS# = ((SumWS2 - (SumWS ^ 2 / NumR%)) / (NumR% - 1)) ^ .5
   SigmaWD# = ((SumWD2 - (SumWD ^ 2 / NumR%)) / (NumR% - 1)) ^ .5
    WriteLabel Row%, 0, 8, TapeID$
      WriteLabel Row%, 1, 6, StartBLK$
    WriteInteger Row%, 2, 7, StartRecord%
    WriteInteger Row%, 3, 7, StartMM%
     WriteNumber Row%, 4, 6, "F1", StartSEC#
```

```
                    NumSec# = NumR% / 10
      WriteNumber Row%, 5, 5, "F1", NumSec#
      WriteNumber Row%, 6, 6, "F2", AvgWS#
      WriteNumber Row%, 7, 6, "F2", SigmaWS#
                    WN# = MinWS
      WriteNumber Row%, 8, 6, "F2", WN#
                    WN# = MaxWS
      WriteNumber Row%, 9, 6, "F2", WN#
     WriteNumber Row%, 10, 6, "F1", AvgWD#
     WriteNumber Row%, 11, 6, "F1", SigmaWD#
                    WN# = MinWD
     WriteNumber Row%, 12, 6, "F1", WN#
                    WN# = MaxWD
     WriteNumber Row%, 13, 6, "F1", WN#
    WriteInteger Row%, 14, 6, MinA%(1)
    WriteInteger Row%, 15, 6, MaxA%(1)
    WriteInteger Row%, 16, 6, MinA%(2)
    WriteInteger Row%, 17, 6, MaxA%(2)
    WriteInteger Row%, 18, 6, MinA%(3)
    WriteInteger Row%, 19, 6, MaxA%(3)
                    WN# = MinS(1)
     WriteNumber Row%, 20, 7, "F3", WN#
                    WN# = MaxS(1)
     WriteNumber Row%, 21, 7, "F3", WN#
                    WN# = MinS(2)
     WriteNumber Row%, 22, 7, "F3", WN#
                    WN# = MaxS(2)
     WriteNumber Row%, 23, 7, "F3", WN#
                    WN# = MinS(3)
     WriteNumber Row%, 24, 7, "F3", WN#
                    WN# = MaxS(3)
     WriteNumber Row%, 25, 7, "F3", WN#
                    WN# = MinS(4)
     WriteNumber Row%, 26, 7, "F3", WN#
                    WN# = MaxS(4)
     WriteNumber Row%, 27, 7, "F3", WN#

     Row% = Row% + 1
skiprite:
     ready = zero
RETURN

' **************** zero out accumulators ********************
ResetVars:
              'PRINT Bfile$, Rec%, NumR%, AvgWS#, AvgWD#,
   NumR% = zero
   SumWS = zero
  SumWS2 = zero
   SumWD = zero
  SumWD2 = zero

   MaxWS = zero: MinWS = athou
   MaxWD = zero: MinWD = athou
   FOR I% = 1 TO 3
     MaxA%(I%) = mnines      ' set the min & max
     MinA%(I%) = pnines      ' values to -9999 and +9999
     MaxS(I%) = mnines
     MinS(I%) = pnines
   NEXT I%
     MaxS(4) = mnines
     MinS(4) = pnines

   StartBLK$ = Bfile$
   StartMM% = MM%
   StartSEC# = SEC
   StartRecord% = Rec%
   ready = 1
 RETURN

' **************** done, cleanup & quit ********************
AllDone:
   GOSUB writeit
'Write the "End of File" record and close file
```

```
Temp = 1                    ' Opcode for end-of-file
PUT FileNum, , Temp
Temp = 0                    ' data length = 0
PUT FileNum, , Temp
LOCATE 12, 20
PRINT "                     Stop Time:"; TIME$

CLOSE
  STOP

WriteColWidth:
     FOR I% = 1 TO 28
           Temp = 8
           PUT FileNum, , Temp
           Temp = 3
           PUT FileNum, , Temp
           Temp = I% - 1
           PUT FileNum, , Temp
           TmpString$ = CHR$(CN%(I%))
           PUT FileNum, , TmpString$
     NEXT I%

RETURN

SUB WriteInteger (Row%, Column%, ColWidth%, Integ%)

           Temp = 13                      ' Opcode for integer
           PUT FileNum, , Temp
           Temp = 7                       'length + 5 byte header
           PUT FileNum, , Temp
           TmpString$ = CHR$(127)              'format portion of the header
           PUT FileNum, , TmpString$
           PUT FileNum, , Column%
           PUT FileNum, , Row%
           PUT FileNum, , Integ%

END SUB

SUB WriteLabel (Row%, Column%, ColWidth%, Msg$)

     IF LEN(Msg$) > 240 THEN Msg$ = LEFT$(Msg$, 240)

           Temp = 15                      ' Opcode for label
           PUT FileNum, , Temp
           Temp = LEN(Msg$) + 7           'len + 5 byte header + ' + CHR$(0)
           PUT FileNum, , Temp
           TmpString$ = CHR$(127)              '127 is default for unprotected cell
           PUT FileNum, , TmpString$
           PUT FileNum, , Column%
           PUT FileNum, , Row%
           TmpString$ = "'" + Msg$ + CHR$(0)'"'"is for left align
           PUT FileNum, , TmpString$

END SUB

SUB WriteNumber (Row%, Column%, ColWidth%, Fmt$, Number#)
     IF LEFT$(Fmt$, 1) = "F" THEN                  ' F = fixed format
        Format$ = CHR$(0 + VAL(RIGHT$(Fmt$, 1)))   'Num dec places
     ELSEIF LEFT$(Fmt$, 1) = "C" THEN              ' C = currency
        Format$ = CHR$(32 + VAL(RIGHT$(Fmt$, 1)))  'Num dec places
     ELSEIF LEFT$(Fmt$, 1) = "P" THEN              ' P = percent
        Format$ = CHR$(48 + VAL(RIGHT$(Fmt$, 1)))  'Num dec places
     ELSE
        Format$ = CHR$(127)                        'default format
        'Format$ = CHR$(255)                        ' option to protect cell
     END IF

           Temp = 14                      ' Opcode for number
           PUT FileNum, , Temp
           Temp = 13
           PUT FileNum, , Temp
           PUT FileNum, , Format$
           PUT FileNum, , Column%
```

```
        PUT FileNum, , Row%
        PUT FileNum, , Number#

END SUB
```

```
'***************** Write data for input to Asystant ******************
'* WL2ASYST.BAS                                                      *
'*     Dick Wood May 89                                              *
'*                                                                   *
'*********************************************************************
OPTION BASE 1
DIM ready AS INTEGER
DIM NUM%(8), L$(8), H$(8)
DIM A(3), MaxA(3), MinA(3)
DIM S(4)
DIM MaxS(4), MinS(4)
af$ = "###.### , ###.### , ###.###"
sf$ = "###.###"
sf$ = "###.### , ###.### , ###.### , ###.###"
 FFA$ = "###.### "
 WF$ = "####.### , ####.##"

  H2000 = 8192
  H1FFF = H2000 - 1
  H1000 = H2000 / 2
  H07FF = 2047
   zero = 0
  athou = 1000
 mnines = -9999
 pnines = 9999

filenum = 2 'FREEFILE      ' get next available file number
CLS
LOCATE 8, 20
PRINT "enter TapeID$";
INPUT TapeID$: Sblock$ = UCASE$(Sblock$)

LOCATE 10, 20
PRINT "enter Starting Block Number ";
INPUT Sblock$: Sblock$ = UCASE$(Sblock$)
LOCATE 14, 20

    dtype$ = "A" + LTRIM$(STR$(WhichS%))
    dtype% = 1

LOCATE 12, 20
PRINT "Output File Name ";
INPUT Filename$: Filename$ = UCASE$(Filename$)


CLS
LOCATE 6, 20
PRINT "Writing ASYSTANT file for "; dtype$
'LOCATE 8, 20
'PRINT "                    Start Time:"; TIME$
    ready = zero
    Jtime = zero
 LastTime = zero
     Rec% = zero
    NumR% = zero
 GOSUB ResetVars
     BLK% = VAL(Sblock$)
     AsysRecs% = 0
'********************************** main loop
 DO
 'OpenInputFile:
    Bfile$ = LTRIM$(STR$(BLK%))
    WHILE LEN(Bfile$) < 4
       Bfile$ = "0" + Bfile$
    WEND
    Bfile$ = "B" + Bfile$
   'IF BLK% < 300 THEN DIR$ = "D:" ELSE DIR$ = "E:"
             DIR$ = "A:"
     'ON ERROR GOTO AllDone
       OPEN "I", #1, DIR$ + Bfile$
       CLOSE #1
    LOCATE 10, 20
    PRINT DIR$ + Bfile$;
```

```
  OPEN "R", #1, DIR$ + Bfile$, 16
  FIELD #1, 1 AS L$(1), 1 AS H$(1), 1 AS L$(2), 1 AS H$(2), 1 AS L$(3), 1 AS H$(3), 1 AS L$(4), 1 AS H$(4), 1 AS L$(5), 1

  BLK% = BLK% + 1

 FOR Rec% = 1 TO 2000
  'Read 8 numbers from file
  GET #1, Rec%
  FOR I% = 1 TO 8
    NUM%(I%) = CVI(L$(I%) + H$(I%))
  NEXT I%

  Datatype% = INT(NUM%(1) / H2000) + 1
  IF Datatype% < 1 OR Datatype% > 4 THEN PRINT R%, ASC(H$), ASC(L$), Datatype%: STOP
   ON Datatype% GOSUB Header, Wind, Accel, AandS
    'IF dtype% = 1 AND Datatype% = 3 THEN GOSUB Accel
    'IF dtype% = 2 AND Datatype% = 4 THEN GOSUB AandS
  IF AsysRecs% >= 4097 THEN GOTO AllDone
 NEXT Rec%
 CLOSE #1
 LOOP
 GOTO AllDone

Header:
  'PRINT R%, "Header"
RETURN

Wind:
   MM% = NUM%(2)
   SEC = NUM%(3) / 10
   WS = NUM%(4) * .08
   WD = NUM%(5) * .54
                          PRINT MM%, SEC, WS, WD
   Jtime = MM% + SEC / 60
   ElapsedTime = Jtime - LastTime
   IF AsysRecs% > 0 AND ElapsedTime > .0025 THEN
      LOCATE 5, 40
      PRINT "BREAK IN TIME "
      GOSUB ResetVars
   END IF

   'IF ready = zero THEN GOSUB ResetVars

   LastTime = Jtime

   SumWS = SumWS + WS
  SumWS2 = SumWS2 + WS ^ 2
   SumWD = SumWD + WD
  SumWD2 = SumWD2 + WD ^ 2

  IF WS > MaxWS THEN MaxWS = WS
  IF WS < MinWS THEN MinWS = WS
  IF WD > MaxWD THEN MaxWD = WD
  IF WD < MinWD THEN MinWD = WD
  IF WD >= 360 THEN WD = WD - 360
  PRINT #4, USING WF$; WS; WD

 NumR% = NumR% + 1
 LOCATE 2, 10: PRINT Jtime, NumR%
 'IF NumR% >= 120 THEN GOSUB writeit
 RETURN

Accel:

    'IF ready = zero THEN RETURN
    NUM%(1) = NUM%(1) AND H1FFF
     IF NUM%(1) AND H1000 THEN
        NUM%(1) = -NUM%(1) AND H07FF
        NUM%(1) = -NUM%(1)
    END IF
    A(1) = 5 * NUM%(1) / athou
    A(2) = 5 * NUM%(2) / athou
    A(3) = 5 * NUM%(3) / athou
```

```
    FOR I% = 1 TO 3
       IF A(I%) < MinA(I%) THEN MinA(I%) = A(I%)
       IF A(I%) > MaxA(I%) THEN MaxA(I%) = A(I%)
        'PRINT A(i%);
     NEXT I%
      IF dtype% = 1 THEN GOSUB WriteAccel
    FOR I% = 1 TO 3
       A(I%) = 5 * NUM%(3 + I%) / athou
       IF A(I%) < MinA(I%) THEN MinA(I%) = A(I%)
       IF A(I%) > MaxA(I%) THEN MaxA(I%) = A(I%)
       'PRINT A(i%);
     NEXT I%
      IF dtype% = 1 THEN GOSUB WriteAccel
      'PRINT
RETURN

AandS:
    'IF ready = zero THEN RETURN
   NUM%(1) = NUM%(1) AND H1FFF
   IF NUM%(1) AND H1000 THEN
       NUM%(1) = -NUM%(1) AND H07FF
       NUM%(1) = -NUM%(1)
   END IF
   A(1) = 5 * NUM%(1) / athou
   A(2) = 5 * NUM%(2) / athou
   A(3) = 5 * NUM%(3) / athou
   IF dtype% = 1 THEN GOSUB WriteAccel

   FOR I% = 1 TO 3
      IF A(I%) < MinA(I%) THEN MinA(I%) = A(I%)
      IF A(I%) > MaxA(I%) THEN MaxA(I%) = A(I%)
       'PRINT A(i%);
    NEXT I%
    IF dtype% = 1 THEN GOSUB WriteAccel
    FOR I% = 1 TO 4
      S(I%) = NUM%(3 + I%) / 120
      IF S(I%) < MinS(I%) THEN MinS(I%) = S(I%)
      IF S(I%) > MaxS(I%) THEN MaxS(I%) = S(I%)
      'PRINT S(i%);
    NEXT I%
     IF dtype% = 2 THEN GOSUB WriteStrain
RETURN

WriteAccel:
    PRINT #filenum, USING FFA$; A(1)
    AsysRecs% = AsysRecs% + 1
    LOCATE 20, 20: PRINT AsysRecs%
RETURN
WriteStrain:
        'PRINT #filenum, USING sf$; S(1); S(2); S(3); S(4)
         PRINT #filenum, USING sf1$; S(WhichS%)
        AsysRecs% = AsysRecs% + 1
    LOCATE 20, 20: PRINT AsysRecs%
RETURN



ResetVars:
CLOSE #2
CLOSE #4

OPEN "C:\ASYSTANT\A1.PRN" FOR OUTPUT AS #2
OPEN "C:\ASYSTANT\WSD.PRN" FOR OUTPUT AS #4
'OPEN "SCRN:" FOR OUTPUT AS #2
 AsysRecs% = 0
  NumR% = zero
  SumWS = zero
 SumWS2 = zero
  SumWD = zero
 SumWD2 = zero


  MaxWS = zero: MinWS = athou
```

```
  MaxWD = zero: MinWD = athou
  FOR I% = 1 TO 3
    MaxA(I%) = mnines
    MinA(I%) = pnines
    MaxS(I%) = mnines
    MinS(I%) = pnines
  NEXT I%
    MaxS(4) = mnines
    MinS(4) = pnines

  StartBLK$ = Bfile$
  StartMM% = MM%
  StartSEC# = SEC
  StartRecord% = Rec%
  ready = 1
RETURN

AllDone:
OPEN "C:\ASYSTANT\" + Filename$ + ".SUM" FOR OUTPUT AS #3
  'GOSUB writeit
  'writeit:
  AvgWS# = SumWS / NumR%
  AvgWD# = SumWD / NumR%
  SigmaWS# = ((SumWS2 - (SumWS ^ 2 / NumR%)) / (NumR% - 1)) ^ .5
  SigmaWD# = ((SumWD2 - (SumWD ^ 2 / NumR%)) / (NumR% - 1)) ^ .5
   'PRINT Bfile$, Rec%, NumR%, AvgWS#, AvgWD#,
      PRINT #3, "TapeID              "; TapeID$
PRINT #3, USING "AvgWS  ###.##    SigmaWS  ###.##  min ###.##  max ###.##"; AvgWS#; SigmaWS#; MinWS; MaxWS
PRINT #3, USING "AvgWD  ###.##    SigmaWD  ###.##  min ###.##  max ###.##"; AvgWD#; SigmaWD#; MinWD; MaxWD
      PRINT #3, "          MIN                    MAX"
FOR I% = 1 TO 4
   PRINT #3, USING " S#      ####.###              ####.###"; I%; MinS(I%); MaxS(I%)
NEXT I%
FOR I% = 1 TO 3
   PRINT #3, USING " A#     #####.###             #####.###"; I%; MinA(I%); MaxA(I%)
NEXT I%

      PRINT #3, "StartBLK$    "; StartBLK$
PRINT #3, USING "NumR%            #####"; NumR%
PRINT #3, USING "StartRecord%     #####"; StartRecord%
PRINT #3, USING "StartMM%          ####"; StartMM%
PRINT #3, USING "StartSEC#          ###"; StartSEC#
PRINT #3, USING "NumSEC#            ###"; NumSEC#

'Write the "End of File" record and close file
LOCATE 12, 20
PRINT "            Number of Records written:"; AsysRecs%

CLOSE
  STOP
```